Lost in Digitalisation? Navigating public transport in the digital era

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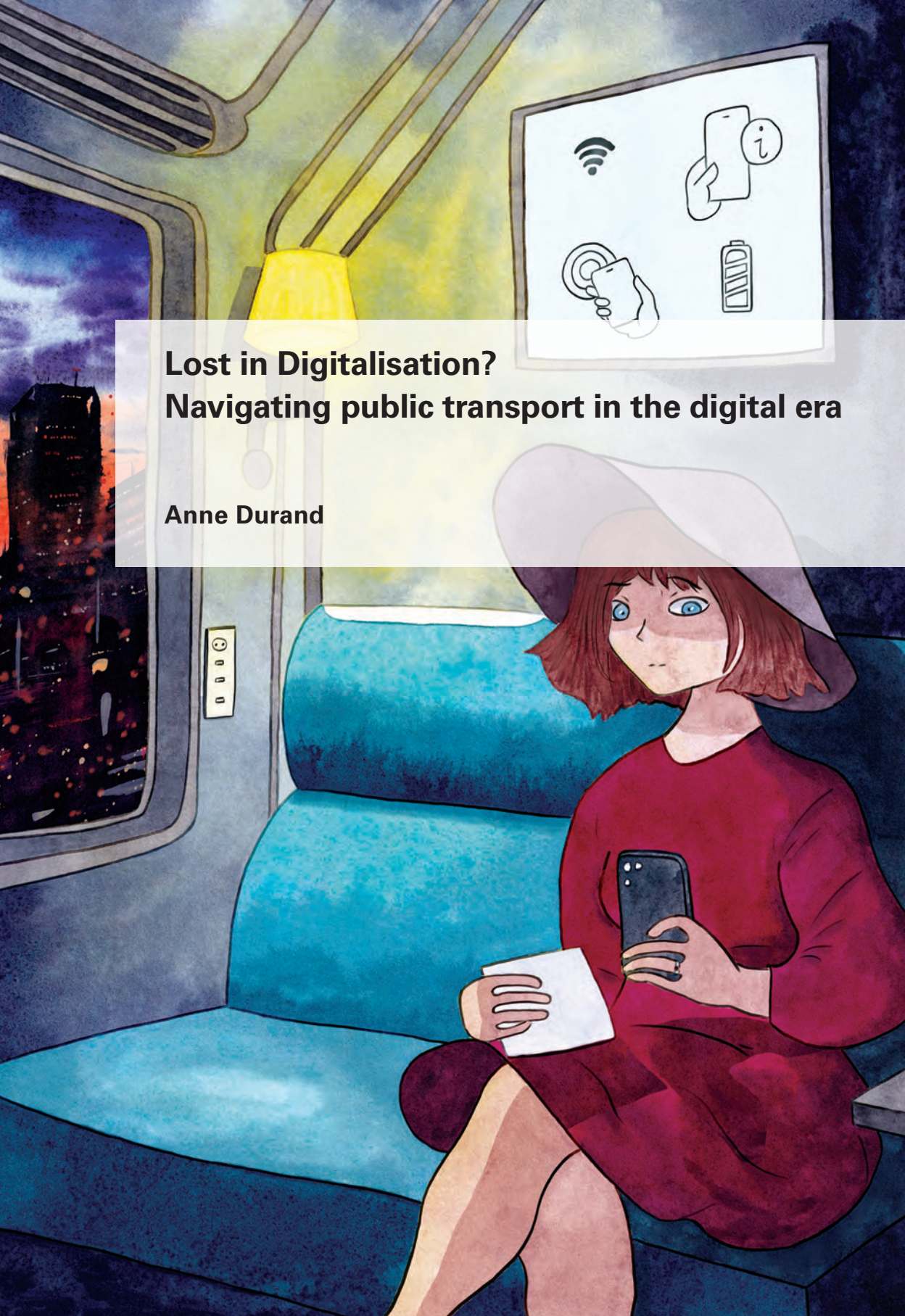

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Anne Durand

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Delft University of Technology

Cover illustration by Anne Durand: ‘Compartment C Car, 2025’.

Inspired by the work of Edward Hopper (1882-1967).

Lost in Digitalisation?
Navigating public transport in the digital era

Dissertation

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chair of the Board for Doctorates,

to be defended publicly on

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by

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Anne

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Content

Summary

Over recent decades, technological advancements have significantly transformed digital technologies and their role in mobility. Information and Communication Technologies (ICTs) have revolutionised how people access and navigate transport systems. Innovations such as navigation systems, multimodal travel information applications and contactless ticketing illustrate this shift. Research highlights the benefits of these technologies for travellers, ranging from decreased perceived waiting times to greater convenience and enhanced perceptions of reliability. Emerging concepts such as smart mobility, including Mobility-as-a-Service (MaaS), are anticipated to address various dimensions of transport disadvantage and promote social inclusion.

However, this framing of digital technologies in transport as potential solutions to societal challenges is increasingly questioned. Notably, benefitting from the possibilities and the opportunities offered by digital technologies is conditioned by the readiness and ability to use them. Certain groups may be made invisible and even excluded from transport services when the existence of disparities in access to digital technologies is overlooked. This concern is especially acute in public transport, a crucial service for the social participation of some people. Against this backdrop, this dissertation aims at understanding the process of digital access and engagement in public transport and the potentially exclusionary effects of digital transformations, as well as identifying approaches to mitigate these effects. To fit this research objective, we blend qualitative and quantitative data and methods. In addition, we adopt a cross-disciplinary perspective by leveraging the theoretical lens of digital inequality from communication science. Most of the studies in this dissertation were conducted in the context of the Netherlands. This country's leading position in digitalisation makes it an interesting case for this dissertation, as it can help others understand and address challenges that are paired with widespread digitalisation in a timely manner.

In the first step of this research (Chapter 2), we investigated how car and public transport users in the Netherlands access and engage with digital technologies for travel-related purposes, as

well as the extent to which these technologies are perceived as necessary. We did so through a questionnaire distributed to representative populations of car and public transport users in the Netherlands. There is clear evidence of travellers getting more used to digital technologies over time. In 2022, approximately 80% of car and public transport users report occasional or frequent reliance on smartphones for accessing travel information. The findings indicate a strong positive correlation between higher self-reported digital skills and the likelihood of using smartphone-based travel information.

There are clear disparities visible within our sample. Older adults, individuals in lower-income households, individuals with lower education levels, and women are more likely to report lower digital skills and experience barriers to digital engagement. Public transport users report higher digital skills than car users, while these samples do not differ significantly in terms of age and education levels. This finding suggests that low (perceived) digital skills might be a barrier to potentially switching from the car to public transport.

Digital technologies have become embedded in travel practices. Three quarters (75%) of car and public transport users think that travelling is more difficult in 2022 without a smartphone, demonstrating a radical shift in societal expectations within a decade and a half. Alternatives like public information displays are still used by a majority of travellers, but traditional communication channels are not deemed sufficient anymore to travel worry-free. These perceptions can contribute to shaping a reality where travellers are expected to be able to rely on personal digital devices, putting those with a lower digital access at a disadvantage.

Secondly, we explored the concept of digital inequality in transport services through a literature review (Chapter 3). This study allowed us to identify individuals who are most at risk of being disadvantaged by the increasing digitalisation in transport services, the barriers they face with digital transformations and how these barriers impact people's mobility and accessibility of locations. Older adults, women, people with lower education levels, with lower income levels, from minorities and from rural areas are more likely to be vulnerable to digitalisation in transport services. Health limitations and literacy issues compound these vulnerabilities. Importantly, the interplay of multiple determinants often explains a reduced access to digital technologies more comprehensively than any single factor does, such as age or income.

Barriers to digital engagement are multifaceted and can be categorised into four main factors: attitudes, material access to digital technologies, digital skills and engagement with ICTs. While much attention has been paid to material access in the past, literature highlights that this alone does not guarantee an effective engagement. Digital skills and engagement remain critical yet underexplored factors in research on digital inequality in transport. Beyond user considerations, it is important to highlight that the design of a technology fundamentally influences the degree of access it provides. In particular, data-driven and algorithm-based technologies can present a pernicious form of digital exclusion from transport services.

Digitalisation in transport services has far-reaching implications. While it can enhance mobility for many, this development risks amplifying existing social inequalities by turning relative disadvantages into absolute ones. For instance, individuals who struggle with digital tools may experience reduced mobility, have fewer travel opportunities and be at a heightened risk of

social exclusion. Still, digital innovations can also bring significant benefits, such as improved accessibility features for individuals with sensory impairments. Nevertheless, empirical evidence on the impacts of digitalisation on (vulnerable) individuals' mobility and especially on their ability to access locations relevant for them remains limited, warranting further investigation.

Thirdly, we explored how individuals who are more likely to struggle with digital transformations, as identified in Chapter 3, experience digitalisation in public transport and the coping strategies they adopt in response to it (Chapter 4). Interviews with individuals reveal a complex interplay of benefits and barriers associated with digital tools. While smart cards and travel apps improve access and convenience for some, low digital skills, a lack of appropriate devices, and complex interfaces create barriers. Digital transformations also demand 'digital flexibility', a meta skill referring to the ability to adapt to the constant changes brought about by digitalisation, such as app updates, cash disappearing or fewer ticket offices. Some interviewed individuals felt implicitly required to be able to access digital travel information, echoing findings from Chapters 2 and 3.

Despite these challenges, difficulties with digitalisation do not always translate into reduced access to public transport. Coping strategies mitigate these barriers, with support from social circles – a partner, children, or friends – being the most common form of coping. Formal assistance from courses, volunteers, or transport staff can also help. However, many coping strategies involve hidden costs, such as additional preparation and stress. These extra efforts often go unnoticed. In addition, this study highlights a 'self-reliance paradox': while digital technologies have contributed to fostering self-reliance among many, those who are less comfortable with these technologies are likely to become even more dependent on others. Yet even support from individuals' social circle can sometimes prove inadequate or insufficient.

We see evidence that digitalisation can contribute to driving some people away from public transport. They might fall back on private means of transport, if available, travel less or less far, or even renounce some activity opportunities. Those facing the most difficulties with digital transformations often experience other forms of transport or social disadvantages, illustrating how social and digital inequalities amplify each other.

Finally, in the last study in this dissertation, we examined potential policy responses to mitigate digital inequality in public transport (Chapter 5). We identified several complementary approaches through expert interviews. First, an inclusive design perspective emphasises the importance of user-centred development early in the design process. Encouraging diversity within design teams and raising awareness of the diversity of user needs among developers also belong to this perspective. A social perspective highlights the need for collaboration with interest groups to tailor solutions, the use of low-tech tools and the necessity to retain quality non-digital alternatives such as service desks. A persuasive perspective focuses on improving communication to increase awareness of the benefits of digital tools, while educational strategies can enhance confidence and skills, promoting a more effective engagement with digital technologies. Finally, securing the issue of unequal access to public transport due to digitalisation at a decision-making level is essential: (semi-)public organisations and operators

need to reappropriate themselves the governance of digitalisation in the sector. This means taking a proactive stance in identifying and addressing bottlenecks and dilemmas around digitalisation in public transport. This study underscores that systemic issues such as poverty and low literacy also need to be addressed to ensure access to public transport for diverse populations.

By employing a mix of qualitative and quantitative methods, this dissertation contributes to the burgeoning body of literature on transport inequality and digital technologies. It demonstrates that, contrary to the prevailing narrative that digital transformations are universally beneficial, they can also constrain mobility and even hinder accessibility of locations, particularly for some individuals who may already be disadvantaged. Through this research, we signal challenges that may be overlooked due to the relative invisibility of those struggling with digital transformations and warn that future developments may exacerbate these challenges.

For policymakers and practitioners striving to create an inclusive and accessible public transport system, actionable strategies are available to mitigate the exclusionary effects of digitalisation, as identified in Chapter 5. These strategies range from practical measures to more strategic, long-term commitments and are likely to benefit public transport users as a whole. The same strategies apply to other transport services, such as shared mobility services, which are increasingly present in the urban landscape. However, these measures entail (financial) costs. We recommend that efforts be prioritised on transport services where (1) alternative modes of transport are limited or non-existent, and (2) travellers have little choice but to use digital technologies to access the service.

Samenvatting

In de afgelopen decennia heeft technologische vooruitgang digitale technologieën en hun rol in mobiliteit aanzienlijk veranderd. Informatie- en communicatietechnologieën (ICT) hebben de manier waarop mensen toegang krijgen tot en navigeren in vervoerssystemen significant omgevormd. Innovaties zoals navigatiesystemen, multimodale reisinformatie-apps en contactloos betalen laten deze verandering goed zien. Onderzoek wijst op de voordelen van deze technologieën voor reizigers, van kortere wachttijden tot meer gemak en een verbeterde perceptie van betrouwbaarheid. Opkomende concepten zoals slimme mobiliteit, waaronder Mobility-as-a-Service (MaaS), worden gezien als kansrijk om verschillende vormen van vervoersongelijkheid aan te pakken en sociale inclusie te bevorderen.

Er wordt echter steeds vaker getwijfeld of digitale technologieën in mobiliteit echt een oplossing kunnen bieden voor maatschappelijke uitdagingen. Het benutten van de mogelijkheden en kansen die digitale technologieën bieden, hangt namelijk sterk af van de bereidheid en het vermogen om ze te gebruiken. Als ongelijkheden in toegang tot digitale technologieën over het hoofd worden gezien, kunnen bepaalde groepen onzichtbaar worden gemaakt of zelfs uitgesloten worden van vervoersdiensten. Deze kwestie is vooral van belang in het openbaar vervoer (ov), dat voor sommige mensen cruciaal is om deel te nemen aan de samenleving. In deze context richt dit proefschrift zich op het begrijpen van het proces van digitale toegang en gebruik van ICT in het openbaar vervoer, de mogelijk uitsluitende effecten van digitale transformaties en het identificeren van oplossingsrichtingen om deze effecten te verminderen. Om dit onderzoeksdoel te bereiken, combineren we kwalitatieve en kwantitatieve data en methoden. Daarnaast hanteren we een interdisciplinair perspectief, waarbij we het theoretische kader van digitale ongelijkheid uit de communicatiewetenschappen toepassen. Het grootste deel van de studies in dit proefschrift is uitgevoerd in Nederland. De leidende positie van dit land op het gebied van digitalisering maakt het een interessante casus. Het kan andere landen helpen de uitdagingen die gepaard gaan met wijdverspreide digitalisering tijdig te begrijpen en aan te pakken.

In de eerste stap van dit onderzoek (hoofdstuk 2) hebben we onderzocht hoe auto- en ov-gebruikers in Nederland toegang hebben tot en gebruik maken van digitale technologieën voor reisgerelateerde doeleinden, en in hoeverre deze technologieën als noodzakelijk worden ervaren. Dit hebben we gedaan aan de hand van een vragenlijst onder representatieve populaties van auto- en ov-gebruikers in Nederland. Het onderzoek toont duidelijk aan dat reizigers steeds meer gewend raken aan digitale technologieën. In 2022 rapporteert ongeveer 80% van de auto- en ov-gebruikers dat ze af en toe of vaak een smartphone gebruiken om reisinformatie op te zoeken. De bevindingen wijzen op een sterke positieve correlatie tussen hogere zelfgerapporteerde digitale vaardigheden en de kans op het gebruik van reisinformatie op een smartphone.

Binnen onze steekproef zijn er duidelijke verschillen zichtbaar. Ouderen, mensen uit huishoudens met een lager inkomen, mensen met een lager opleidingsniveau en vrouwen rapporteren vaker lagere digitale vaardigheden en ervaren barrières bij het gebruik van digitale hulpmiddelen. Ov-gebruikers rapporteren hogere digitale vaardigheden dan automobilisten, terwijl deze groepen niet significant verschillen qua leeftijd en opleidingsniveau. Deze bevinding suggereert dat lage (ervaren) digitale vaardigheden een barrière kunnen vormen voor een eventuele overstap van de auto naar het openbaar vervoer.

Digitale technologieën zijn ingebed geworden in de manier waarop we reizen. Drie kwart (75%) van de auto- en ov-gebruikers denkt dat reizen in 2022 moeilijker is zonder smartphone. Dit illustreert een radicale verschuiving in maatschappelijke verwachtingen binnen anderhalf decennium. Alternatieven zoals openbare informatieborden worden nog steeds door een meerderheid van de reizigers gebruikt, maar traditionele communicatiekanalen worden niet meer voldoende beschouwd om zorgeloos te reizen. Deze percepties dragen bij aan een werkelijkheid waarin van reizigers wordt verwacht dat zij kunnen vertrouwen op hun eigen digitale hulpmiddelen, wat mensen met minder toegang tot digitale middelen benadeelt.

Ten tweede hebben we het concept van digitale ongelijkheid in vervoersdiensten door middel van een literatuurstudie onderzocht (hoofdstuk 3). Met deze studie hebben we groepen in de samenleving geïdentificeerd die het grootste risico lopen om benadeeld te worden door de toenemende digitalisering in vervoersdiensten. Ook hebben we geïdentificeerd de barrières waarmee ze geconfronteerd worden bij digitale transformaties en hoe deze barrières hun mobiliteit en bereikbaarheid beïnvloeden. Ouderen, vrouwen, mensen met een lager opleidingsniveau, een lager inkomen, uit minderheden of woonachtig in landelijke gebieden zijn waarschijnlijk kwetsbaarder voor digitalisering in transport. Gezondheidsbeperkingen en laaggeletterdheid vergroten deze kwetsbaarheden. Belangrijk is dat het samenspel van meerdere determinanten vaak een betere verklaring biedt voor een beperkte toegang tot digitale technologieën dan een enkele determinant, zoals leeftijd of inkomen.

Barrières voor digitale participatie zijn veelzijdig. We verdelen ze onder in vier hoofdfactoren: attitudes, materiële toegang tot digitale hulpmiddelen, digitale vaardigheden en gebruik van ICT. Hoewel er in het verleden veel aandacht aan materiële toegang werd besteed, benadrukt de literatuur dat deze factor op zichzelf geen effectieve participatie garandeert. Digitale vaardigheden en het gebruik van digitale technologieën zelf zijn kritieke maar onderbelichte

aspecten in onderzoek naar digitale ongelijkheid in transport. Daarbovenop is het belangrijk om te benadrukken dat het ontwerp van technologie een fundamentele rol speelt in de mate van toegankelijkheid. Met name datagedreven en algoritmische technologieën kunnen een verraderlijke vorm van digitale uitsluiting van vervoersdiensten veroorzaken.

Digitalisering van vervoersdiensten heeft verregaande gevolgen. Hoewel deze de mobiliteit van velen kan verbeteren, dreigt deze ontwikkeling bestaande sociale ongelijkheden te versterken door relatieve nadelen om te zetten in absolute nadelen. Zo kunnen mensen die moeite hebben met digitale hulpmiddelen minder mobiel worden, minder reismogelijkheden hebben en een groter risico lopen op sociale uitsluiting. Niettemin kunnen digitale innovaties ook belangrijke voordelen met zich meebrengen, zoals verbeterde toegankelijkheidsfuncties voor personen met zintuiglijke beperkingen. Desondanks blijft het empirische bewijs van de effecten van digitalisering op de mobiliteit en vooral op de bereikbaarheid van (kwetsbare) groepen in de samenleving beperkt, wat verder onderzoek noodzakelijk maakt.

Ten derde hebben we onderzocht hoe mensen die waarschijnlijk meer moeite hebben met digitale transformaties (zoals geïdentificeerd in hoofdstuk 3), de digitalisering in het openbaar vervoer ervaren en welke strategieën zij hanteren om hiermee om te gaan (hoofdstuk 4). Uit interviews met deze mensen blijkt er een complex samenspel te bestaan van voordelen en belemmeringen bij het gebruik van digitale hulpmiddelen. Hoewel een chipkaart of reisapp de toegang tot het ov en het reisgemak voor sommigen verbeteren, zorgen lage digitale vaardigheden, een gebrek aan geschikte hulpmiddelen en complexe interfaces juist voor barrières. Digitale transformaties vereisen daarnaast ‘digitale flexibiliteit’, een metavaardigheid die verwijst naar het vermogen om zich aan te passen aan constante veranderingen door digitalisering. Voorbeelden hiervan zijn app-updates, het verdwijnen van contant geld en minder fysieke loketten. Sommige geïnterviewden geven aan zich impliciet verplicht te voelen om toegang te hebben tot digitale reisinformatie, wat aansluit bij bevindingen uit hoofdstuk 2 en 3.

Ondanks deze uitdagingen vertalen problemen met digitalisering zich niet altijd in een verminderde toegang tot het openbaar vervoer. Mensen ontwikkelen copingsstrategieën om deze barrières te overkomen, waarbij steun vanuit sociale netwerken – zoals een partner, kinderen of vrienden – de meest voorkomende vorm van hulp is. Formele hulp van cursussen, vrijwilligers of vervoerspersoneel kan ook helpen. Veel van deze strategieën brengen echter verborgen kosten met zich mee, zoals extra voorbereiding en stress. Deze inspanningen blijven vaak onopgemerkt. Bovendien wordt in dit onderzoek een ‘zelfredzaamheidsparadox’ zichtbaar: hoewel digitale technologieën zelfredzaamheid bij velen bevorderen, worden mensen die minder vertrouwd zijn met deze hulpmiddelen juist vaker afhankelijk van anderen. Zelfs steun vanuit het sociale netwerk blijkt soms ontoereikend of onvoldoende.

We zien aanwijzingen dat digitalisering ertoe kan bijdragen dat sommige mensen het openbaar vervoer links laten liggen. Ze vallen terug op privévervoermiddelen, indien beschikbaar. Of ze reizen minder, of minder ver, of zien zelfs af van bepaalde activiteiten. Degenen die de meeste moeite hebben met digitale transformaties ervaren vaak andere problemen op het vlak van vervoer of op andere terreinen. Dit illustreert hoe sociale en digitale ongelijkheden elkaar versterken.

In de laatste studie van dit proefschrift hebben we mogelijke beleidsmaatregelen onderzocht om digitale ongelijkheid in het openbaar vervoer te verminderen (hoofdstuk 5). Uit interviews met experts komen verschillende benaderingen naar voren, die elkaar aanvullen. Ten eerste wordt met een inclusief ontwerpperspectief het belang van een vroege betrokkenheid van gebruikersgroepen benadrukt. Diversiteit bevorderen binnen ontwerpteams en meer bewustzijn vergroten over de uiteenlopende behoeften van gebruikers onder ontwikkelaars zijn ook onderdeel van dit perspectief. Ten tweede wordt met een sociaal perspectief samenwerking met belangengroepen aangemoedigd om oplossingen op maat te maken. Dit perspectief kan onder andere betekenen dat lowtechtools moeten worden ingezet of dat kwalitatieve niet-digitale alternatieven zoals loketten moeten worden behouden. Een persuasief perspectief richt zich op het verbeteren van de communicatie om het bewustzijn van de voordelen van digitale hulpmiddelen te vergroten. Het vierde perspectief heeft met educatie te maken, waarbij vaardigheden en (zelf)vertrouwen vergroot kunnen worden. Dit leidt tot een effectiever gebruik van digitale hulpmiddelen. Ten slotte is het cruciaal dat ongelijke toegang tot het openbaar vervoer door digitalisering wordt aangepakt op het niveau van de organisaties zelf: (semi)publieke organisaties en vervoerders moeten de regie (governance) over de digitalisering van de sector in eigen hand houden. Dit houdt in dat zij proactief knelpunten en dilemma's rondom digitalisering in het openbaar vervoer identificeren en aanpakken. Daarnaast benadrukken we in deze studie dat systemische problemen zoals armoede en laaggeletterdheid ook aangepakt moeten worden om toegang tot het openbaar vervoer voor diverse bevolkingsgroepen te waarborgen.

Door gebruik te maken van een mix van kwalitatieve en kwantitatieve methoden draagt dit proefschrift bij aan de groeiende literatuur over vervoersongelijkheid en digitale technologieën. Het toont aan dat, in tegenstelling tot het dominante verhaal dat digitale transformaties universeel gunstig zijn, ze ook mobiliteit kunnen beperken en zelfs bereikbaarheid kunnen belemmeren. Dit geldt vooral voor mensen die al in een kwetsbare positie verkeren. Dit onderzoek signaleert uitdagingen die vaak over het hoofd worden gezien vanwege de relatieve onzichtbaarheid van degenen die moeite hebben met digitale transformaties. Bovendien waarschuwt het voor toekomstige ontwikkelingen die deze uitdagingen mogelijk kunnen verergeren.

Voor beleidsmakers en deskundingen in de praktijk die streven naar een inclusiever en toegankelijker openbaar vervoersysteem, bestaan er concrete manieren om de mogelijk uitsluitende effecten van digitalisering te verminderen. Deze manieren hebben we in hoofdstuk 5 beschreven. Ze variëren van praktische maatregelen tot strategische, langetermijnverplichtingen en zijn waarschijnlijk gunstig voor alle bestaande en toekomstige ov-gebruikers. Dezelfde strategieën kunnen worden toegepast op andere vervoersdiensten, zoals deelmobiliteitsdiensten. Deze diensten zijn in toenemende mate (vooral in de stad) beschikbaar. De maatregelen die we beschrijven, brengen echter (financiële) kosten met zich mee. We raden aan prioriteit te geven aan vervoersdiensten waar (1) alternatieve vervoerswijzen beperkt of niet beschikbaar zijn, en (2) reizigers afhankelijk zijn van digitale technologieën om toegang te krijgen tot de vervoersdienst.

Résumé

Au cours des dernières décennies, les avancées technologiques ont considérablement transformé les technologies du numérique et leur rôle dans la mobilité. Les technologies de l'information et de la communication (TIC) ont révolutionné la manière dont les individus accèdent aux systèmes de transport et y naviguent. Des innovations telles que les systèmes de navigation, les applications multimodales d'information et la billettique sans contact illustrent cette évolution. La recherche a déjà mis en évidence les avantages de ces technologies pour les voyageurs, comme une réduction des temps d'attente perçus, une plus grande facilité pour se déplacer et une perception de meilleure fiabilité du réseau. Dans ce contexte, des concepts émergents tels que la mobilité intelligente (smart mobility), y compris la mobilité comme service (MaaS), sont vus comme des moyens de remédier aux inégalités d'accès aux transports et de promouvoir l'inclusion sociale.

Cependant, cette conception des technologies en matière de mobilité comme des solutions potentielles aux défis sociétaux est de plus en plus remise en question. En effet, bénéficier des possibilités et des opportunités offertes par les technologies numériques est conditionné par la volonté et la capacité de les utiliser. Négliger l'existence de telles disparités dans l'accès aux technologies numériques peut entraîner une invisibilisation, voire une exclusion, de certaines personnes des services de transport. Cette préoccupation est particulièrement aiguë dans les transports en commun, un service crucial pour la participation sociale de certaines personnes. Dans ce contexte, cette thèse vise à comprendre le processus d'accès au numérique et de son utilisation dans les transports en commun, les potentiels effets d'exclusion des transformations digitales, ainsi qu'à identifier des approches permettant d'atténuer ces effets. Pour répondre à cet objectif de recherche, nous combinons des données et des méthodes qualitatives et

quantitatives. En outre, nous adoptons une perspective interdisciplinaire en nous appuyant sur le cadre conceptuel des inégalités d'accès aux technologies du numérique issu des sciences de la communication. La plupart des études de cette thèse ont été menées dans le contexte des Pays-Bas. La position de leader de ce pays en matière de transformations digitales en fait un cas intéressant pour cette thèse, car il peut en aider d'autres à comprendre et répondre aux défis liés à la digitalisation de manière opportune.

Dans la première étape de cette recherche (chapitre 2), nous avons étudié la manière dont les usagers de la voiture et des transports en commun aux Pays-Bas accèdent aux technologies numériques et les utilisent pour se déplacer, ainsi que la mesure dans laquelle ces technologies sont perçues comme nécessaires. Pour ce faire, nous avons distribué un questionnaire à des populations représentatives d'usagers de la voiture et des transports en commun aux Pays-Bas. Il apparaît clairement que les voyageurs s'habituent de plus en plus aux technologies numériques au fil du temps. En 2022, environ 80 % des usagers de la voiture et des transports en commun aux Pays-Bas déclarent utiliser fréquemment ou occasionnellement un smartphone pour accéder à des informations pour leurs déplacements. Les résultats indiquent une forte corrélation positive entre des compétences numériques déclarées élevées d'une part, et la probabilité d'accéder à des informations pour ses déplacements sur un smartphone d'autre part.

Des disparités évidentes sont visibles au sein de notre échantillon. Les personnes âgées, les personnes issues de ménages à faibles revenus, les personnes ayant un niveau de scolarisation relativement bas et les femmes sont généralement plus susceptibles de déclarer des compétences numériques faibles et d'être confrontées à des obstacles pour l'utilisation du numérique lors de leurs déplacements. Les usagers des transports en commun font état de compétences numériques plus élevées que les automobilistes, alors que ces échantillons ne présentent pas de différences significatives en termes d'âge et de niveau de scolarisation. Ces résultats suggèrent que de faibles compétences numériques (déclarées) pourraient constituer un obstacle pour un éventuel report modal de la voiture aux transports en commun.

Les technologies numériques font désormais partie intégrante des pratiques de déplacement. Trois quarts (75 %) des automobilistes et utilisateurs de transports en commun aux Pays-Bas pensent qu'il est plus difficile de se déplacer sans smartphone en 2022, témoignant d'un changement radical dans les attentes sociétales en l'espace d'une quinzaine d'années. La majorité des voyageurs utilise encore des outils tels que des écrans d'information (le long de la route ou en gare). Toutefois, en règle générale, les outils de communication traditionnels ne sont plus jugés suffisants pour se déplacer sans souci. Ces perceptions peuvent contribuer à façonner une réalité dans laquelle les voyageurs sont censés pouvoir s'orienter et se déplacer avec leurs propres outils numériques. Cela désavantage ceux qui ont un accès plus limité au numérique.

Deuxièmement, nous avons exploré le concept d'inégalités d'accès aux technologies numériques dans les services de transport (incluant les transports en commun) via une synthèse des travaux existants à ce sujet (chapitre 3). Cette étude nous a permis d'identifier les individus qui risquent le plus d'être désavantagés par la digitalisation croissante dans les services de transport, les obstacles qu'ils rencontrent avec les transformations digitales et la manière dont ces obstacles impactent leur mobilité et accessibilité. Les personnes âgées, les femmes, les

personnes ayant un bas niveau de scolarisation, issues de ménages à faibles revenus, les minorités et les habitants de zones rurales sont plus susceptibles d'être vulnérables à la digitalisation dans les services de transport. Les problèmes de santé et d'alphabétisation aggravent ces vulnérabilités. Il est important de noter que l'interaction de multiples déterminants explique souvent un accès réduit aux technologies numériques de manière plus complète qu'un seul facteur, tel que l'âge ou le revenu.

Les obstacles à l'utilisation du numérique sont multiples et peuvent être classés en quatre catégories principales : les attitudes, l'accès matériel aux technologies numériques, les compétences numériques et l'utilisation concrète des TIC. Si l'accès matériel a fait l'objet d'une grande attention dans le passé, la littérature souligne qu'il ne garantit pas à lui seul une utilisation efficace des outils du numérique. Les compétences numériques et l'utilisation même des TIC restent des facteurs essentiels mais peu explorés dans la recherche sur les inégalités d'accès aux technologies numériques dans les transports. Au-delà des considérations relatives à l'utilisateur, il convient de souligner que la conception d'une technologie influence fondamentalement le degré d'accès qu'elle offre. En particulier, les technologies basées sur des (méga)données numériques et des algorithmes peuvent constituer une forme pernicieuse d'exclusion numérique des services de transport.

La digitalisation des services de transport a des implications considérables. Si elle peut améliorer la mobilité de nombreuses personnes, elle risque d'amplifier les inégalités sociales existantes en transformant des désavantages relatifs en désavantages absolus. Par exemple, les personnes qui ont du mal à utiliser les outils numériques peuvent voir leur mobilité réduite, avoir moins de possibilités pour se déplacer et courir un risque accru d'exclusion sociale. Néanmoins, les innovations numériques peuvent également apporter des avantages significatifs, comme des améliorations pour l'accessibilité des personnes en situation de handicap, par exemple via des applications pour personnes malvoyantes. Toutefois, les preuves empiriques de l'impact de la digitalisation sur la mobilité des personnes (vulnérables) et en particulier sur leur aptitude à se rendre dans des endroits qui leur sont importants restent limitées et méritent d'être approfondies.

Troisièmement, nous avons exploré la manière dont les individus les plus susceptibles d'être vulnérables aux transformations digitales, telles qu'identifiées au chapitre 3, vivent la digitalisation dans les transports en commun et les stratégies d'adaptation qu'ils adoptent pour y faire face (chapitre 4). Des entretiens semi-directifs avec ces individus révèlent une interaction complexe entre des avantages et des obstacles associés aux outils numériques. Si les cartes de transport sans contact et les applications sur téléphone améliorent l'accès aux transports et la facilité de se déplacer pour certains, de faibles compétences numériques, un manque d'outils appropriés et des interfaces complexes créent des obstacles pour d'autres. Les transformations digitales exigent également une "flexibilité numérique". Il s'agit d'une méta-compétence désignant la capacité à s'adapter aux changements constants induits par la digitalisation, tels que les mises à jour d'applications, la disparition de l'argent liquide ou la réduction progressive du nombre de guichets en gare. Certaines personnes interrogées se sentent implicitement obligées d'être en mesure d'accéder à des informations numériques pour leurs déplacements, faisant écho aux conclusions des chapitres 2 et 3.

Malgré ces défis, les difficultés liées à la digitalisation ne se traduisent pas toujours par un accès réduit aux transports en commun. Des stratégies d'adaptation atténuent ces obstacles. Le soutien des cercles sociaux - conjoint, enfants ou amis - est la forme d'aide la plus courante. L'aide formelle apportée par des cours, des bénévoles ou le personnel des transports peut également s'avérer utile. Cependant, de nombreuses stratégies d'adaptation impliquent des coûts cachés, tels qu'une préparation et un stress supplémentaires. Ces efforts supplémentaires passent souvent inaperçus. En outre, cette étude met en évidence un "paradoxe de l'autonomie" : si les technologies numériques ont contribué à favoriser une certaine forme d'autonomie dans les transports pour de nombreuses personnes, celles qui sont moins à l'aise avec ces technologies risquent de devenir encore plus dépendantes des autres. Pourtant, même le soutien du cercle social peut parfois s'avérer inadéquat ou insuffisant.

Nous constatons que la digitalisation dans les transports en commun peut contribuer à éloigner certaines personnes de ce type de service. Ces personnes-là peuvent alors se rabattre sur des moyens de transport privés, s'ils sont disponibles, ou voyager moins ou moins loin, ou même renoncer à certaines activités. Les personnes qui rencontrent le plus de difficultés avec les transformations digitales sont souvent confrontées à d'autres types de difficultés pour se déplacer ainsi qu'à une certaine forme de précarité sociale, illustrant la façon dont les inégalités sociales et numériques s'amplifient l'une et l'autre.

Enfin, dans la dernière étude de cette thèse, nous avons examiné les réponses potentielles pour atténuer les inégalités d'accès aux technologies numériques dans les transports en commun (chapitre 5). Des entretiens avec des experts nous ont permis d'identifier plusieurs approches complémentaires. Tout d'abord, une perspective de conception inclusive est importante : elle souligne l'importance d'un développement technologique centré sur l'utilisateur dès le début du processus de conception. Encourager la diversité au sein des équipes de conception et sensibiliser les développeurs à la diversité des besoins des utilisateurs sont aussi des actions qui s'inscrivent dans cette perspective. Deuxièmement, une perspective sociale met l'accent sur la collaboration avec des groupes d'intérêt pour adapter les solutions. L'utilisation d'outils low-tech et la conservation d'alternatives non numériques de qualité, telles que des guichets de service, font aussi partie de cette démarche sociale. Une perspective persuasive se concentre sur l'amélioration de la communication pour accroître la sensibilisation aux avantages des outils numériques, tandis que les stratégies éducatives peuvent renforcer la confiance et les compétences, promouvant une utilisation plus efficace des outils numériques. Enfin, il est essentiel d'aborder la question de l'inégalité d'accès aux transports en commun due à la digitalisation à un niveau décisionnel. Les organisations (semi-)publiques et les exploitants de transports en commun doivent se réapproprier la gouvernance de la digitalisation dans le secteur. Cela signifie d'adopter une position proactive, en identifiant et en traitant les points de blocage et les dilemmes liés à la digitalisation dans les transports en commun. Notre étude souligne que des problèmes systémiques tels que la pauvreté et un faible niveau d'alphabétisation doivent également être abordés afin de garantir un accès aux transports en commun pour diverses populations.

En utilisant un mélange de méthodes qualitatives et quantitatives, cette thèse contribue à l'essor de la littérature sur les inégalités d'accès aux transports et les technologies numériques. Elle

démontre que, contrairement à l'idée reçue selon laquelle les transformations digitales sont universellement bénéfiques, elles peuvent également restreindre la mobilité et même entraver la possibilité de certains à se rendre à leurs activités, en particulier ceux étant déjà en situation précaire. Grâce à cette recherche, nous signalons des défis qui peuvent être négligés en raison de l'invisibilité relative de ceux qui rencontrent des difficultés liées aux transformations digitales. Nous mettons aussi en garde contre de potentiels développements futurs qui pourraient exacerber ces défis.

Pour les décideurs politiques et les professionnels du secteur des transports en commun s'efforçant de créer un système de transport inclusif et accessible, il existe des façons d'atténuer les effets indésirables de la digitalisation, comme indiquées au chapitre 5. Ces façons vont de mesures pratiques à des engagements plus stratégiques sur le long terme, et sont susceptibles d'être bénéfiques aux usagers des transports en commun dans leur ensemble. Ces mêmes stratégies peuvent s'appliquer à d'autres services de transport, tels que les services de mobilité partagée, qui sont de plus en plus nombreux dans le paysage urbain. Cependant, ces mesures ont un coût (financier). C'est pourquoi nous recommandons de concentrer les efforts sur les services de transport pour lesquels (1) les modes de transport alternatifs sont limités ou inexistants, et (2) les voyageurs n'ont guère d'autre choix que d'utiliser les technologies numériques pour accéder au service.

Chapter 1: Introduction

1.1 Background

After a couple of decades of unparalleled technological advances, expectations around digital technologies and the role they would play in future everyday mobility were high at the turn of the century. In the Netherlands, the Rathenau Institute – a technology assessment institute – was drafting future scenarios in the late 1990s about the state of transport telematics in 2025 (Achterhuis & Elzen, 1998). In one of these scenarios, an individual '*pulls the* PTM (personal travel mate) *he just got today out of his pocket*' (Achterhuis & Elzen, 1998, p.16; own translation in italic). The character then proceeds to compare the information displayed on a digital screen in an airship with information given by the PTM.

While the predictions of Achterhuis and Elzen on airships were off the mark, their vision of connected devices fitting in a pocket and used to navigate transport was prescient (though these objects arrived much faster than they had expected). With the exponential growth of the internet in the 1990s and the increased sophistication of mobile communication technologies around the turn of the century, ICTs (Information and Communication Technologies) have changed and keep changing the way people get access to and navigate transport (Blythe, 2004; Docherty et al., 2018; Mezghani, 2008; Van Der Horst, 2006). Contactless ticketing, navigation systems, smartphone-based ticketing and travel applications such as multimodal planners are prime examples of these technologies. Users possess tools (e.g., a smart card, a smartphone or a navigation system) and use these to navigate information or get access to a system.

Over the years, transport researchers have gotten increasingly interested in travellers' use of ICTs, and the benefits they reap from that usage. For instance, reviews by Brakewood and Watkins (2019) and Bian et al. (2021) present the benefits of public transport (PT) travellers' use of (smartphone-based) real-time travel information. These benefits include decreased (perceived) waiting times, increased use of public transport and increased perceptions of reliability. Benefits of using navigation systems or navigation apps among car users have also

been covered and include shorter travel times (Feenstra et al., 2008; Ramos, 2016; Van Essen et al., 2019) and less uncertainty (Feenstra et al., 2008; Metz, 2022) amongst others.

Furthermore, studies have been anticipating future potential benefits of digital technologies in transport. According to a review of 99 papers by Butler et al. (2020), smart mobility – a term used to refer to transport-related technologies – has the potential to alleviate multiple dimensions of transport disadvantage, from physical to psychological barriers to travel. For instance, some argue that Mobility-as-a-Service (MaaS) will contribute to more social inclusion, by simplifying the process of planning and making a door-to-door trip (Butler et al., 2020).

However, scholars have started questioning the narratives presenting MaaS and digital technologies in transport in general as a solution to social, environmental and health challenges (Banister, 2019; Docherty et al., 2018; Hensher et al., 2020; Lucas, 2019; Lyons et al., 2018; Macharis & Geurs, 2019; Pangbourne et al., 2020). They draw attention to the unanticipated implications of these technologies, such as (further) transport disadvantage and social exclusion. Indeed, a problem with many studies on ICTs in transport is that they take individuals' access to and engagement with digital technologies for granted. Yet benefitting from the possibilities and the opportunities offered by digital technologies is conditioned by the readiness and ability to use them. This concern about unequal access to digital technologies to navigate transport is not new (Draijer, 1997; Spittje & Witbreuk, 2005). Yet the nature and scale of transformations in transport in the years following the release of the first smartphone in 2007 makes this topic more relevant than ever (Aguiléra & Rallet, 2016).

The matter of differences in digital access and engagement among travellers is particularly pressing in transport services, such as public transport and shared mobility services (like shared cars or bicycles), where individuals have arguably less agency with the pace of digitalisation than in the case of privately-owned forms of transport. When digital transformations discard or omit non-digital options and are not carefully introduced and integrated, not wanting or not being able to engage with ICTs might translate into a new form of disadvantage, or even social exclusion (Golub et al., 2022; Martinez et al., 2024; Pritchard et al., 2015). This is particularly problematic as public transport is often the backbone of urban mobility (European Commission, 2021; UITP, 2016), and a crucial service for the social participation of some people, especially those without access to a driver's licence and/or a car (Bigby et al., 2011; Ryan et al., 2015; Stanley & Stanley, 2021; Witte et al., 2022).

This research aims to understand how digitalisation in public transport affects its users and potential users, with a specific focus on those with difficulties engaging with digital technologies. Since digital transformations are likely to keep developing in the future, this dissertation also aims to present approaches to mitigate the potentially exclusionary effects of digitalisation in public transport. By doing so, this dissertation addresses multiple scientific gaps, which are described in the following section.

1.2 Research gaps

Since individuals' access to digital technologies in transport has often been taken for granted, researchers have started collecting data to understand access to and engagement with ICTs in transport in recent years (Golub et al., 2022; Goodman-Deane et al., 2024; Groth, 2019; Zhang et al., 2020). While these studies offer valuable insights into users and non-users of digital technologies in transport, they have limitations on at least two key areas.

First, studies examining the process of digital engagement – the extent to which people access ICTs and subsequently engage with them – tend to focus on public transport users. This is valid given the importance of public transport as stated in previous section; however, it means that we cannot compare how users of different transport modes access and engage with digital technologies, as there is no data available. Yet there are indications that a modal shift from the car to public transport – a pillar to make transport more sustainable (Müller & Reutter, 2022; Sims et al., 2014) – is at least partly predicated on one's ability to retrieve travel information (Ravensbergen et al., 2022; Schmitt et al., 2019). To the best of our knowledge, the latest study comparing car and public transport users in terms of digital engagement dates from more than a decade ago (Farag & Lyons, 2012). Besides, studies do not usually track how access to digital technologies in transport has evolved over the years, while such information would be insightful to better understand digital transformations.

A second key limitation is that existing studies do not assess the extent to which people perceive digital technologies to be necessary, and how these perceptions relate to digital engagement. Groth (2019) attempted to measure these perceptions, but their statements were not specific to transport and did not end up into a single factor after data reduction. This knowledge gap matters because perceptions about technologies contribute to shaping realities (Asmar et al., 2020a; Lin & Silva, 2005) and transmitting societal norms (DiMaggio & Garip, 2012). A widespread societal expectation to be digitally equipped and savvy can put those (temporarily) without (the required hardware/skills) at a disadvantage (Lupač, 2018). These two limitations in existing literature lead us to the following research gap:

- **Research gap 1: A lack of understanding of digital engagement among both car and public transport users, and how necessary they perceive digital technologies to be for travel.**

Research on digital transformations in transport as potential barriers to travel is relatively new and still fragmented. We do not have a distinct picture of who is most likely to be disadvantaged by digital transformations (determinants of digital access and engagement), nor do we have a clear overview of the ways in which these transformations raise barriers and impact people's mobility and accessibility of meaningful activities (Banister, 2019; Hensher et al., 2020; Lucas, 2019; Lyons et al., 2018; Macharis & Geurs, 2019). On a conceptual level, these barriers echo the notions of transport disadvantage (Currie & Delbosc, 2011; Schwanen et al., 2015) and transport-related social exclusion (Jeekel, 2018; Kenyon et al., 2002; Lucas, 2012). However,

existing research remains unconnected with these well-established concepts in the transport literature.

In the past years, reviews on the intersection between ICTs and mobility have covered a variety of angles, from the debate around substitution and complementarity of ICTs and travel, to the experience and use of travel time and space (Aguiléra, 2019; Aguiléra et al., 2012; Andreev et al., 2010; Gössling, 2017; Hjorthol, 2008; Van Wee et al., 2013). However, the perspective of how various levels of access to and engagement with digital technologies affect access and navigation of transport services among diverse groups of individuals – digital inequality in transport services – has not been considered. This is lead to the following research gap:

- **Research gap 2: A lack of understanding of digital inequality in transport services, particularly the determinants of digital access and engagement, and how digital transformations may raise barriers and impact people's mobility and accessibility of locations**

As mentioned in research gap 1, researchers have started investigating the process of digital engagement in transport in recent years through quantitative surveys (Golub et al., 2022; Goodman-Deane et al., 2024; Groth, 2019; Zhang et al., 2020). Because surveys need to be concise, these studies do not provide a thorough understanding of the mechanisms behind digital inequality in transport services: how difficulties with digitalisation in transport services emerged and manifest, their potential link with other forms of (social) disadvantage, and how people cope in the face of difficulties. The latter aspect is particularly understudied in transport (Currie & Delbosc, 2011). These mechanisms are best understood at a meso level – that is, 'the everyday social, physical, and technical environments in which people live their lives' (Helsper, 2021, p. 24).

Besides, previous qualitative studies on difficulties with digitalisation in transport services usually focus on one specific group, mainly older adults (Bertolaccini & Hickman, 2019; Butler et al., 2021; Carney & Kandt, 2022; Gould, 2020; Harvey et al., 2019; Kos-Łabędowicz, 2020). These studies offer relevant insights, yet they do not allow for conclusions to be drawn across multiple groups of individuals in society. In addition, most of the aforementioned qualitative studies already focus on emerging transport services, overlooking existing issues with public transport. These gaps in literature lead us to the following research gap to be addressed in this dissertation:

- **Research gap 3: Limited knowledge about mechanisms of digital inequality in public transport**

In an inclusive society where public transport is a public service, difficulties in accessing and using public transport need to be addressed (Dutch College for Human Rights, 2023; United Nations Convention on the Right of Persons with Disabilities, 2024). Many public transport professionals are already familiar with ways to enable barrier-free travelling for people with a

physical or auditory impairment. From lifts at stations to level access and auditory guidance, best practices have been shared within the sector for decades already (European Commission, 1999; European Railway Agency, 2015; United Nations Development Programme, 2010). Examples of improvements can be found in the Netherlands (ProRail, 2021) and in Japan (Dobashi & Ohmori, 2018). However, unlike issues linked with physical and sensory accessibility, tackling difficulties stemming from digitalisation is a relatively new task for transport practitioners and policymakers (Macharis & Geurs, 2019; Pinto et al., 2023).

As digital developments in public transport have taken place at a fast pace (Van Dijck et al., 2018), we lack an understanding of solutions to tackle the accessibility issues these developments are causing. At best, fragmented responses are put forward, with a sole focus on digital accessibility for people with a sensory impairment for instance (Delaere et al., 2021). At worst, policymakers and practitioners may not respond at all. This leads us to the following research gap:

- **Research gap 4: A fragmented and incomplete understanding of approaches to foster an inclusive public transport system in the digital era**

1.3 Research objective and questions

Based on the research gaps identified in the previous section, the overarching research objective considered in this dissertation is as follows:

'To understand the process of digital access and engagement in public transport and the potentially exclusionary effects of digital transformations, as well as approaches to mitigate these effects.'

To fulfil this objective, we formulate four research questions that we intend to answer through this research:

1. *How do car and public transport users access and engage with digital technologies for travel-related purposes, and to what extent do they perceive them to be necessary?*
2. *Which individuals are most at risk of being disadvantaged by the increasing digitalisation of transport services, what do we know about the barriers that they face with digital transformations and how these barriers impact people's mobility and accessibility of locations?*
3. *How do groups that are more at risk of digital inequality experience digital transformations in public transport, and what are the coping strategies they might have developed in response to it?*
4. *What are possible policy approaches to mitigate digital inequality in public transport?*

1.4 Theoretical and conceptual framework

In communication science, studying disparities in terms of digital access and engagement, as well as their consequences is known as digital inequality research. This dissertation adopts a cross-disciplinary perspective by applying this lens of digital inequality in the field of transport. This approach is needed according to Robinson et al. (2015), who write that 'digital inequality should not be only the preserve of specialists but should make its way into the work of social scientists concerned with a broad range of outcomes connected to life chances and life trajectories.' (p. 570).

Multiple theories and models of digital inequality co-exist. Transport researchers are usually acquainted with theories using the acceptance of technology perspective, but these are less informative of digital inequality. For instance, the Theory of Planned Behaviour (Ajzen, 1991) or the Diffusion Of Innovation theory (Rogers, 1962, 2003) only cover the first phases of access to a technology, lack a feedback loop and fail to acknowledge the complexity of adoption of a technology (Lupač, 2018; Selwyn, 2004).

A well-known and established theory of digital inequality is the causal and sequential model of digital media access, originally described by Van Dijk (2005). It focuses on the exclusion of individuals due to the integration of ICTs in all aspects of society. Unlike many other theories of digital inequality, it is not restrained to a spatial context or a given field (Mariën et al., 2016), which makes it transposable to the field of transport. This causal and sequential model of digital media access has been extensively tested and validated (Van Deursen et al., 2017; Van Deursen & Van Dijk, 2015). This model is being used as a base for other, slightly different models, one of which will be introduced below when discussing drawbacks of the model originally established by Van Dijk (2005).

The conceptual framework used throughout this dissertation is shown in Figure 1.1. Van Dijk's model assumes that socioeconomic, sociodemographic and other personal factors (like health) lead to different resources (time, money, etc.). These resources influence the extent to which one accesses and subsequently engages with digital technology, where the process of engagement consists of four successive factors: motivation, material access, digital skills and usage (or engagement). These factors are influenced by the characteristics of technologies. This process of engagement influences participation outcomes and, in turn, resources.

The model originally established by Van Dijk has two notable drawbacks. First, it may look like a linear model; yet it can also be read in a circular manner (Van Dijk, 2019). For instance, the fact that gaining skills influences attitudes on technology is included. Besides, research has shown that it is not necessary to have fully completed one factor to be able to access the next one (Van Deursen, 2018). The model of socio-digital inequalities of Helsper (2021) (Corresponding Fields model), which shares many similarities with van Dijk's model and was inspired by it, solves this readability issue by employing double arrows.

Second and most importantly, a main criticism is motivation as an entry point. As ICTs are becoming increasingly ubiquitous and profoundly entangled in institutions and daily practices, motivation is no longer the precondition to access technology it used to be (Mariën et al., 2016).

Indeed, digital access has become the default option in many systems (digital by default) and the individual ability to deal with this digital push may be what increasingly shapes digital inequality, instead of being motivated to use digital technologies. To better investigate digital inequality, it is necessary to assess how indispensable ICTs are in a given context according to Lupač (2018), by examining how embedded these technologies are in everyday routines and in institutions of this field, and how available non-ICT alternatives are. Instead of 'motivations and attitudes', Helsper (2021) use the term 'dispositions', referring to 'motivations, attitudes, norms and values'. Lupač's notion of indispensability would then fit in this list as a 'norm'.

Both points of criticism do not invalidate Van Dijk's model though. We use them to update the modal originally suggested by Van Dijk, as shown in Figure 1.1. This figure presents the general conceptual framework used throughout this dissertation; Chapters 2 to 6 will use or show slightly different views and names on this model, but the base remains the same.

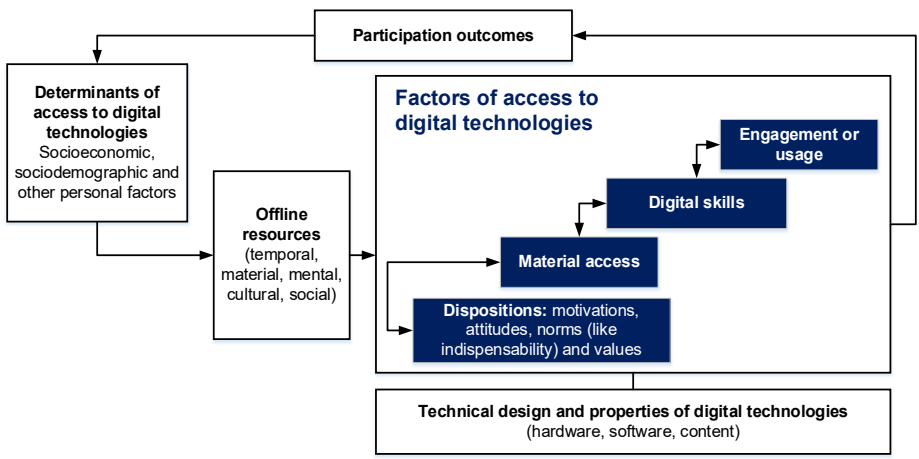

Figure 1.1: Conceptual framework to investigate the process of digital engagement and its consequences (inspired by Van Dijk's model (Van Dijk, 2005, 2019), adapted with Helsper's model of socio-digital inequalities (Helsper, 2021) and Lupač's (2018) notion of indispensability).

1.5 Data collection and methods

This dissertation uses a blend of qualitative and quantitative data and methods, to fit the research objective. Chapter 2 is quantitative in nature while the following ones are based on qualitative data (analysis). The methods used to analyse qualitative data differ between Chapters 3, 4 and 5 because of the nature of the collected data and research objectives. The (data collection) methods for each chapter are described below.

- **Chapter 2: A quantitative survey (N=1,657) analysed with descriptive and regression analyses (Durand et al., 2024).**

  This chapter makes use of data collected in 2022 through the Mobility Panel Netherlands (MPN), an annual online panel designed for the longitudinal study of travel behaviour in the Netherlands (see Hoogendoorn-Lanser et al. (2015)). Our questionnaire focused specifically on the smartphone and on digital travel information services, enabling us to establish connections between socioeconomic variables, sociodemographic variables, travel behaviour and digital access. The choice for this instrument was motivated by two aspects:

  - The MPN has the advantage that we know a lot about respondents' travel behaviour. This gives us the unique opportunity to select and reach representative samples of public transport and car users at a large-scale (national) level (net samples: N=685 and N=972, respectively). Note that the representativeness is done on four variables: age, gender, education level and travel mode frequency.

  - A few questions linked to digital access have already been used in the MPN in 2018 (see Zijlstra et al. (2020)), thereby allowing us to track evolutions within 4 years' time among the same respondents (N=370).

  The collected data were analysed in SPSS Statistics 29. After descriptive analyses, we used a data reduction technique (Exploratory Factor Analysis, EFA) to look for relationships among our data. We subsequently conducted two Ordinary Least Square (OLS) regression analyses and two binary logistic regression analyses to uncover variables that explain different factors of access to digital technologies. The variables ultimately included in the models were selected through a careful process of hierarchical regression (see Field (2018)) based on their potential importance (based on previous research), their contribution to a better fit of the model, and their low correlation with other variables included in the model.

- **Chapter 3: A literature review of 25 papers analysed with a directed content analysis (Durand et al., 2022).**

  This chapter is based on a review of scientific papers in the literature at the nexus of digitalisation, social exclusion and mobility. We used five queries in Scopus in English to identify relevant studies in 2020 and proceeded to follow the PRISMA guidelines (Moher et al., 2009). Titles, keywords and abstracts of journal papers, conference proceedings and book chapters were screened using the web application Rayyan (Ouzzani et al., 2016). This tool allows for a smoother and quicker screening process by providing semi-automation features. We also applied forward and backward snowballing techniques on relevant papers. We included 25 papers, subsequently analysed through a directed content analysis. This is a deductive process which implies starting the analysis with a theory as guidance (Hsieh & Shannon, 2005), in our case the framework presented in section 1.4.

- **Chapter 4: Semi-structured interviews analysed with a flexible coding approach (Durand et al., 2023c)**

  This chapter relies on 39 one-on-one semi-structured interviews conducted between 2020 and 2021 with older adults, people with a lower education level, people with impairments and people with a migration background in the Netherlands. Semi-structured interviews entail a set of clear instructions in a topic list to be followed by the interviewer, yet with enough freedom to follow leads from the interviewee (Russell Bernard, 2011, pp. 157–158).

  We used two purposive sampling techniques – maximum variation sampling and intensity sampling, see Patton (2014) – to recruit participants who have some difficulties using digital technologies, and with various levels of experience with public transport. Participants were recruited through key contact persons in welfare and care institutions, a nation-wide organisation for people with low literacy levels, workplaces for people with impairments, community centres as well as advocacy groups for people with a mild cognitive impairment and for older adults.

  The transcripts of the interviews were analysed through a qualitative data analysis software (ATLAS.ti 9) using a flexible coding approach (Deterding & Waters, 2018). Flexible coding comes from sociology and entails a set of procedures providing a transparent analysis framework, leveraging on the capabilities of modern qualitative data software. We used a blend of deductive and inductive approaches and reflected on our position as researchers investigating individuals in situations of disadvantage.

- **Chapter 5: Semi-structured interviews with experts analysed with qualitative content analysis (Durand et al., 2023d)**

  This chapter uses 22 interviews conducted between 2020 and 2021 with experts working either in the public transport sector or in other sectors also undergoing digital transformations, such as healthcare and public administration. The experts were sampled to ensure a diversity in expertise based on their experience and knowledge.

  Transcripts of the interviews were analysed in ATLAS.ti 9 through a qualitative content analysis. We chose this type of analysis because we were looking for a category-based analysis method, where 'the analytical categories are the focus of the analysis process' (Kuckartz, 2014, p. 68). We also wanted to select a type of analysis suitable for practice-oriented data such as our expert interviews. In fact, other researchers have used this type of analysis for expert interviews (see e.g. Zerwas (2019)). To ensure that our results were as valid and complete as possible, we used two techniques:

  - We triangulated data, by using more than one method to gather insights on the same topic (Flick, 2009). In addition to expert interviews, we collected insights from literature (see Chapter 3) and interviews with individuals at risk of digital exclusion in public transport (see Chapter 4).

- We verified our measures and perspectives through respondent validation (Ritchie & Lewis, 2003). That way, we checked that we had not missed out on measures and that our list of possible measures made sense. We did so by presenting our results to an expert on digital inequality and digital inclusion previously interviewed, and by organising a 2-hour online workshop with 20 public transport experts (a few of them had already been interviewed). This step allowed us to get feedback on our preliminary results and to deepen our understanding of the barriers to apply certain measures.

1.6 Contributions and relevance of the research

Given the objective of the dissertation, this research presents multiple contributions that are relevant both for the scientific community and for society.

1.6.1 Contributions to science

Of all ten dimensions of transport-related social exclusion as presented by Luz and Portugal (2021), the 'digital divide' component is one of the most understudied (Bruno et al., 2024). This dissertation contributes to the burgeoning body of literature on transport equity by investigating disparities in access to and engagement with digital technologies and resulting differential impacts. The specific scientific contributions of each chapter are described below:

- **Chapter 2: New insights into the (process of) digital engagement among car and public transport and into perceptions of indispensability among travellers (Durand et al., 2024).**

  The collected data allow us to provide new insights, as we use representative samples of car and public transport users, where previous studies use a general sample of the population or a sample of public transport users. In addition, since we use a longitudinal panel, we are also able to examine evolutions of a few components of digital engagement over a period of four years. Our subsequent analyses also allow us to provide new insights. In particular, we explain digital engagement using both mobility-related variables (public transport or car use frequency, frequency of unfamiliar trips) and a variable capturing digital skills, where previous quantitative research usually does not have access to both variables (Dodel & Hernandez, 2025; Wybraniec et al., 2024; Zhang et al., 2020). In addition, we operationalised the notion of indispensability, drawing on Lupač's (2018) conceptualisation.

- **Chapter 3: Introducing digital inequality research in transportation research (Durand et al., 2022).**

  We introduce for the first time research on digital inequality (from the field of communication science) into the field of transport science and link it with the concepts of transport disadvantage and transport-related social exclusion. We provide a conceptual framework that structures the concept of digital inequality applied in transport services, we synthesise the literature on digital inequality in transport services and highlight gaps in literature and topics where further research efforts are needed.

- **Chapter 4: A richer understanding of mechanisms behind digital inequality in public transport, and a rigorous application and explanation of a qualitative method (Durand et al., 2023c).**

  This chapter provides a richer understanding of mechanisms behind digital inequality in public transport by:

  1. Investigating difficulties with digitalisation across multiple groups in society, while previous qualitative research tends to focus on specific groups, notably older adults. This allows us to draw overarching conclusions on mechanisms of digital inequality in public transport.
  2. Analysing patterns in our results and meanings beneath the semantic surface. This way, we go beyond a simple description of benefits and difficulties associated with digital transformations in transport. Notably, we draw from psychology research by Lazarus and Folkman (1984) on coping strategies and apply this concept as well as their transactional stress model for the first time in transport research. This allows us to develop a person-centred understanding of the mechanisms behind digital inequality in public transport.

  Methodologically, we provide extensive details about our method, which is not usual for qualitative research in transport (not even in sociology, see Deterding and Waters (2018)). We detail our theoretical lens (critical realism), which often missing in qualitative research in general (Braun & Clarke, 2019). We also specify our purposive sampling techniques – seldom mentioned in qualitative transport research –, our data collection, and a step-by-step description of our flexible coding approach as introduced by sociologists Deterding & Waters (2018).

- **Chapter 5: Using an interdisciplinary approach to define and organise measures to foster inclusion in public transport in the digital era (Durand et al., 2023d).**

  Involving stakeholders with expertise in other fields than transport allows for a strong theoretical contribution. Indeed, we show how the transport sector can get inspired by other sectors with a more mature understanding of digital transformations and needs not reinvent the wheel for each new challenge.

  Methodologically, we present and apply a type of qualitative data analysis that is particularly suitable for practice-oriented data and demonstrate how the techniques of data triangulation and respondent validation can be used to enhance the dependability and the credibility of the study results.

1.6.2 Societal relevance

Making cities inclusive is one of the seventeen Sustainable Development Goals set by the United Nations (United Nations, n.d.). The UN's Convention on the Rights of Persons with Disabilities (CRPD), translated in Europe into the European Accessibility Act (EAA), requires everyday products and services to be accessible to persons with disabilities and to people with

functional limitations. This includes 'any physical, mental, intellectual or sensory impairments, age-related impairments, or other human body performance related causes, permanent or temporary, which, in interaction with various barriers, result in their reduced access to products and services' (European Commission, n.d.). In parallel, ministries or departments responsible for transportation policies have published reports highlighting the need for transport services to be inclusive and accessible to all (see e.g. Dutch Ministry of Infrastructure and Water Management (2021, 2022); Dutch Ministry of Health Welfare and Sport (2024)). In addition to the scientific contributions, this dissertation provides valuable insights to policymakers, public transport operators and authorities, as well as other stakeholders working on digital technologies in transportation. We highlight here three specific contributions of our research for society:

- **Signalling existing issues in transport.**

  Difficulties with digitalisation are often less well-understood by decision-makers and transport planners than physical or sensory accessibility issues, and too often interpreted as an older adults' problem only. Unlike people with a physical or sensory impairment, individuals having difficulties with digitalisation are harder to identify and therefore easily (involuntarily) made invisible (Bonnetier et al., 2019). This dissertation sheds light on the current challenges faced by certain groups in society who are less comfortable with (the pace of) digitalisation in transport, and the sometimes insidious consequences of technological innovations on them.

- **Indicating future potential issues in transport.**

  Many public authorities and researchers share the expectation that digital technologies will contribute to a more inclusive transportation system, as outlined in section 1.1, but also to a more sustainable transportation system (Aguiléra, 2019; Gössling, 2017). With the opportunity to leverage on smart mobility services to transition towards less car-dependent patterns, the trend to rely on ICTs in transport is likely to keep going on (Banister, 2019; Groth, 2019). 'Smart' and 'green' often go hand in hand (Lödder et al., 2017). Nevertheless, Manders and Klaassen (2019) caution that sustainability and social aspects are often linked to technological solutions as 'an incidental benefit rather than a prioritised aim' (p. 7) in the general smart mobility discourse. Not only does this dissertation shed light on current issues pertaining to digitalisation, it also helps stakeholders anticipating potential inclusivity issues in a transport system relying increasingly on ICTs.

- **Interacting with stakeholders and presenting them approaches to foster inclusion in the digital era.**

  Chapter 5 of this dissertation focuses on measures to mitigate the potentially exclusionary effects of digital transformations in public transport. These measures were inspired by existing good practices and co-created with policymakers, public transport operators and authorities, as well as other stakeholders working on digital technologies in transportation.

1.7 Context of the research

1.7.1 Geographical scope: the Netherlands

Apart from our literature review study (Chapter 3), all studies presented in this dissertation were conducted in the context of the Netherlands. In this country, the public transport sector has been actively leveraging on the opportunities offered by digitalisation in the past years (Council for the Environment and Infrastructure, 2021; Government of the Netherlands, 2021). A smart card has been available nation-wide since 2012 (Van Oort et al., 2015), buses have been cashless since 2018 (OVPro.nl, 2018) and the amount of ticket offices in stations has been halved in 2022 (SpoorPro.nl, 2022). Online trip planning via a connected device is widespread and started in the early days of the smartphone: the first public transport planning app (or rather, website adapted for smartphone) was available in 2008, just a year after the introduction of the smartphone (De Bruin, 2009).

While the Netherlands is the frontrunner in Europe in terms of (mobile) internet coverage and basic digital skills (Statistics Netherlands, 2023a), there are important differences in the population. 19% of the population aged 12 and older has no or low digital skills, but this statistic rises to 21% for people with a non-western migration background, 36% for people with a lower education level and 43% for people over 65 (Statistics Netherlands, 2019). One in six people aged 16 or older have low numeracy and/or literacy skills (Netherlands Court of Audit, 2016), which likely translates into difficulties navigating the digital world (Van Deursen & Van Dijk, 2014). In turn, this can impact access to travel information, with negative outcomes on mobility (Hong et al., 2020).

1.7.2 Transferability of the findings

The position of the Netherlands as a frontrunner in terms of digitalisation, coupled with what we know about differences between various groups in society, makes the Netherlands an interesting case for this dissertation. This may at first glance seem to be a rather narrow focus; however, we provide detailed descriptions about our context, which allows for the transferability of findings (see also the discussion on generalisability in section 6.2.3). Most notably, Chapters 2, 4 and 5 can help researchers and policymakers in other countries understand inclusivity challenges that are paired with widespread digitalisation and identify unintended consequences in a timely manner. This way, this dissertation contributes to the body of literature from the Netherlands in English that analyses lessons to be learnt from implementing digital products and services (Manders et al., 2018; Peeters & Widlak, 2018; Rachovitsa & Johann, 2022; Van Den Hurk et al., 2021; Van Houwelingen et al., 2018).

1.8 Dissertation outline

While this dissertation mainly focuses on public transport, Chapters 2 and 3 take a slightly broader approach, as depicted in Figure 1.2. Chapter 2 investigates the digital engagement among both car and public transport users, and how necessary digital technologies are perceived

to be to travel nowadays (**Research gap 1**). Next, Chapter 3 is a review of the literature on digital inequality in transport services (**Research gap 2**).

Chapters 4 and 5 both focus on digital transformations in public transport, using the Netherlands as a research context. Chapter 4 uncovers mechanisms behind digital inequality in public (**Research gap 3**). Chapter 5 is a logical progression after the previous chapters and addresses approaches to foster an inclusive public transportation system in the digital era (**Research gap 4**). Finally, we summarise the main conclusions from our research in Chapter 6, as well as its implications for practice and for future research.

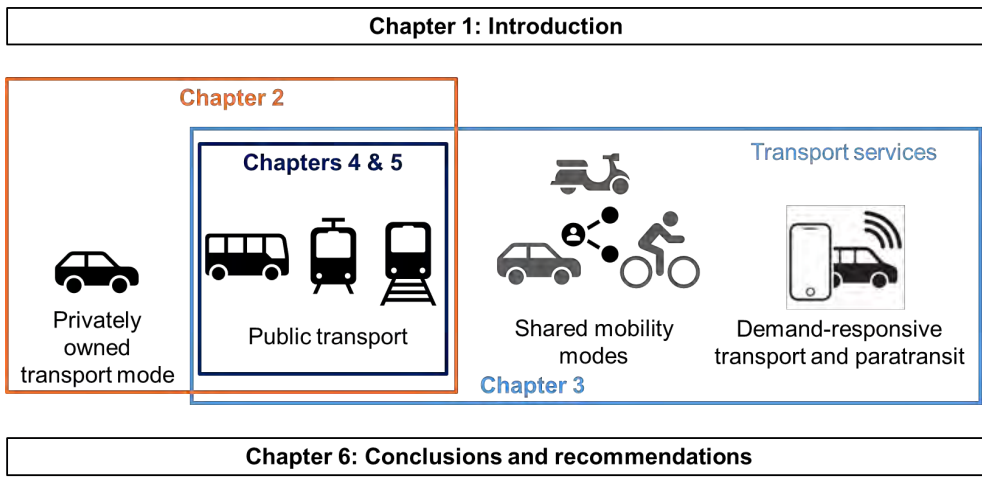

Figure 1.2: Dissertation outline and scope in terms of analysed transportation modes.

Chapter 2: Digital engagement for travel information among car and public transport users in the Netherlands

As the offer of digital services in transport expands, understanding users' digital engagement and how it developed over time is important to make informed policy decisions. In particular, we lack an understanding of how both PT (public transport) and car users access and engage with digital technologies and perceive them to be necessary to travel. This chapter bridges this gap, using a 2022 survey of representative samples from both populations in the Netherlands.

After an introduction (section 2.1), section 2.2 explains the concepts of digital access, digital engagement and necessity of digital technologies. Then, research methods and data are explained in section 2.3. Section 2.4 presents our results, from perceptions of necessity of digital technologies in transport to travellers' engagement with digital technologies. The article closes with a discussion and a conclusion in section 2.5, where the implications of this study are clearly underlined.

This chapter is based on the following article:

Durand, A., Hamersma, M., van Oort, N., Hoogendoorn, S. (2024) Digital engagement for travel information among car and public transport users in the Netherlands. *Transportation Research Interdisciplinary Perspectives, 28*, 101285, DOI: 10.1016/j.trip.2024.101285

Restrictions apply to the data that support the findings of this study, as the data contain information that could compromise the privacy of research participants. The data are available upon request. Access conditions and procedures can be found at https://www.mpndata.nl/.

2.1 Introduction

From government welfare to banking services, many services that people use nowadays are mostly or only online, often through a 'digital-by-default' approach (Yates et al., 2015). This is also the case in transport, where (real-time) travel information has become a fundament in the digitalisation of transport (Ben-Elia & Avineri, 2015; Yigitcanlar et al., 2024).

Despite the advantages digitalisation brings to many people in term of travel efficiency, this development puts populations that are less comfortable with digital tools at risk. In recent years, transport scholars have increasingly drawn attention to the potentially exclusionary effects of transport relying a lot, or solely, on the use of Information and Communication Technologies (ICTs) (or digital engagement[1]) from its users (Durand et al., 2022; Keserü & Randhahn, 2023). Researchers have also collected data to understand digital access and engagement in transport, at the scale of countries (Goodman-Deane et al., 2024), regions or cities (Golub et al., 2022; Groth, 2019; Zhang et al., 2020).

While these studies offer valuable insights into the broader impacts of digital developments, they have limitations on at least three key areas. First, they do not track how digital engagement has evolved over the years, while such information would be insightful to better understand digital transformations. A second limitation is their lack of assessment of perceptions of the necessity of digital engagement and how these perceptions might influence actual digital participation. Insight into such societal expectations would contribute to a better understanding of the extent to which a system has indeed become digital by default. Groth (2019) attempted to measure these perceptions, but their statements were not specific to transport and did not end up into a single factor after data reduction, leaving a gap on that matter. Last but not least, most studies examining digital access and engagement tend to focus on public transport (PT) users (e.g. Un et al. (2022), Goodman-Deane et al. (2021)). This means that there is no data available to compare the digital engagement of users of different transport modes, while there are indications that a modal shift from the car to public transport is at least partly predicated on one's ability to retrieve travel information (Ravensbergen et al., 2022; Schmitt et al., 2019). To the best of our knowledge, the latest study comparing car and public transport users in terms of digital engagement dates from more than a decade (Farag & Lyons, 2012).

The goal of this study is to provide insights into the (process of) digital engagement of public transport and car users, and to shed more light on developments related to this digital engagement. Our study uses a survey distributed in 2022 among representative populations of PT and car users in the Netherlands. Our survey was distributed among participants of a longitudinal household panel, allowing us to track changes among some of our respondents between 2018 and 2022. We focus more on the smartphone than on other digital tools as smartphone-based services play such a central role in transportation systems nowadays (Yigitcanlar et al., 2024). We also place more emphasis on digital travel information services,

[1] According to digital inequality scholar Ellen Helsper, 'digital engagement' is more appropriate than 'ICT use' because the latter suggests that technologies are embedded and invisible, while they always exist in the background.

since both car and PT users can use these services (unlike digital ticketing services, which are mostly in PT).

This study offers relevant insights for policymakers and transport professionals internationally. The Netherlands is one of the leaders on the European scene in terms of digitalisation (European Commission, 2022a). It is particularly interesting to examine digital engagement and perceptions around the necessity of such an engagement in the context of a country at the forefront of digitalisation, as it allows other countries to better understand the ins and outs of widespread digitalisation. Besides, this snapshot in time of digital engagement as well as developments in digital engagement in transport can help transport decision-makers make informed policy decisions about future technological advances in the transport sector (Vrščaj et al., 2020).

2.2 Digital engagement and necessity of digital technologies

2.2.1 Digital engagement and its process

For a long time, digital engagement or ICT use boiled down to whether people had a computer and an internet connection or not, and were motivated to go online (Lupač, 2018). As the internet has become more widely accessible over the years, communication science researchers have developed and tested frameworks to describe and explain various degrees of digital engagement (Pick & Sarkar, 2016).

Besides the clear contribution of sociodemographic, socioeconomic and cultural aspects to explain digital engagement, four main components are frequently used to describe and explain *the process of digital engagement*, also called *digital access*: *motivation*, *material access*, *digital skills* and finally, *usage* or *engagement* itself (Helsper, 2021; Van Dijk, 2019). Motivation and material access are still used to explain digital engagement, with the latter no longer being limited to having an internet connection; nowadays, material access also covers the quality and the diversity of (peripheral) devices (smartphones, tablet, printers, etc.) one possesses (Van Deursen & Van Dijk, 2018). Digital skills cover various types of skills, from technical know-how to more strategic skills allowing users to evaluate content's quality and trustworthiness (Van Dijk & Van Deursen, 2014). Engagement is about the frequency of use of the internet and digital technologies, the type of activity performed and the duration of use (Van Dijk, 2005).

2.2.2 Necessity of digital technologies

In their literature review on digital inequality in transport, Durand et al. (2022) (Chapter 3 of this dissertation) explained that several researchers in communication science are critical about *motivation* being the entry point to understand digital access. As digital technologies are becoming increasingly ubiquitous, *motivation* is no longer the main precondition to access technology it used to be. In a digital-by-default ecosystem, motivations matter less than they used to in the early internet days because alternatives to digital technologies are limited or

invisibilised (Mariën et al., 2016). Lupač (2018) theorised this notion of necessity, which they call *indispensability*. How indispensable a digital engagement is, is highly contextual and depends on two aspects according to Lupač (2018):

- The level of embeddedness of a given digital technology in everyday routines and institutions,
- The availability of non-ICT alternatives, factoring in potential costs (time, money, energy, etc.) to access these alternatives.

In this study, we measure perceptions of indispensability, using the definition provided by Lupač (2018) as a starting point. We will also operationalise motivation, material access, skills and usage as explained in next section.

2.3 Methods and data

2.3.1 Choice of instrument: Netherlands Mobility Panel

We chose a household panel representative of the Dutch population to conduct our study, the Netherlands Mobility Panel (Mobiliteitspanel Nederland, MPN). The MPN is an annual online panel designed for the longitudinal study of travel behaviour in the Netherlands (see Hoogendoorn-Lanser et al. (2015)). In addition to the annual panel waves, MPN respondents occasionally take part in specific surveys, like the one designed for the current study. The choice for this instrument was motivated by two aspects:

- A few questions linked to digital access have already been used in the MPN in 2018 (see Zijlstra et al. (2020)), thereby allowing us to track evolutions within 4 years' time among the same respondents.
- The MPN has the advantage that we know a lot about respondents' travel behaviour. This gives us the unique opportunity to select and reach representative samples of PT and car users at a large-scale (national) level. Note that the representativeness is done on four variables: age, gender, education level and travel mode frequency.

The use of this online instrument means we cannot guarantee that we have representative samples in terms of digital engagement of all Dutch PT and car users. However, according to Statistics Netherlands (2023a, 2023b), 97% of the Dutch population aged 12 and older had access to internet at home in 2022 and 74% had at least basic digital skills in 2021. Besides, note that a recent national report on digital inclusion in the Netherlands, acknowledged as a trusted source, also made use of an online questionnaire only (Van Deursen, 2023). Nevertheless, we understand that the digital engagement we will measure through this instrument will likely be an overestimation of the real digital engagement of car and PT users.

2.3.2 Survey design

2.3.2.1 Target population

We have two target populations: adult (18 years and older) public transport users, and adult car users with a driver's license. We consider people to be 'users' when they use a certain transport mode at least 6 times per year. This is because we want respondents to be able to recall how they usually search for travel information. Since these samples are representative, some PT users will also be car users, and vice-versa. Both car drivers and passengers are counted as car users. The rationale for including car passengers is that they can also assist a driver to look for travel information. We only selected passengers with a driver's license so that they would have a better understanding of the driver's information needs.

2.3.2.2 Survey questions and statements

We kept our survey short since this MPN survey was also used for other research purposes. This meant that we had to be selective about the attitudinal statements (displayed in Table 2.1) and questions used to capture digital access (motivation, material access, skills and engagement) and perceptions of indispensability. A short explanation of the statements and questions we used is provided below.

For *perception of indispensability*, we got inspired by statements from Groth (2019) for #1, #2 and #3. We added statement #4 to have a second statement capturing the availability and usefulness of alternatives to personal ICTs. This statement was carefully chosen after deliberation between the authors, and after testing alternative statements with colleagues.

For the *motivation* component, we used four statements relating to the openness to digital technologies. Research shows that people who are more interested in digital tools – more "tech-savvy" – are more likely to use smartphone applications for transport-related purposes (Astroza et al., 2017; Jamal & Habib, 2020; Zijlstra et al., 2020). See statements #5 to #8. Note that statements #6 and #7 are repeated from Zijlstra et al. (2020) who used the same longitudinal panel as we did; therefore, we will be able to track evolutions among the same respondents between 2018 and 2022.

Material access does not necessarily require statements, as we can simply ask respondents whether they own devices. Still, given the state of research on digital inequality (see section 2.1), we decided to design three statements (#9 to #11) to capture the perception individuals have of the quality of their smartphone. In the field of transport, Golub et al. (2019) showed that the absence of a data bundle as well as battery and storage issues can hinder the use of a smartphone while on-the-go. Note that we will be able to track evolutions among the same respondents between 2018 and 2022 in terms of smartphone ownership.

We translated *digital skills* into a series of four statements (#12 to #15), as inspired by or copied from previous research. For *engagement*, a broad aspect, we specifically inquired about travel information devices and sources used by car and PT users (not shown in Table 1).

All statements were presented as a 5-point Likert scale. We also included a "No opinion" option to identify the extent to which respondents would feel addressed by statements. For the statements pertaining to skills, we replaced "No opinion" with "I don't know", in accordance with recommendations on measuring digital skills through statements (Van Deursen et al., 2014). Note that we kept all statements similar for both car and PT users to allow for comparisons and simultaneous analyses.

Table 2.1: Statements on the perception of indispensability of digital technologies, on motivation, material access and digital skills.

Theorised factors		#	**Statement**	**Copied from or inspired by (when applicable)**
Perception of indispensability of digital technologies	Level of embeddedness	1	Travelling is more difficult without a smartphone.	Groth (2019)
		2	Navigation systems, travel apps and websites are needed in order to travel nowadays.	Alonso-González et al. (2020) Groth (2019)
	Availability of non-(personal) ICT alternatives	3	I can always travel where I want to, even if I don't have any digital travel information.	Groth (2019)
		4	Public information displays like signs along the road or in public transport provide enough information to be able to travel worry-free.	-
Motivation: openness to digital technologies		5	I like trying out new apps and digital services.	Caiati (2017)
		6	It's not a problem for me to use my smartphone, tablet or computer to book products or services (like tickets).	Zijlstra et al. (2020)
		7	It's not a problem for me to use my smartphone, tablet or computer to pay for products or services (like tickets).	Zijlstra et al. (2020)
		8	I avoid the use of digital tools when possible.	Caiati (2017)
Material access: perceived smartphone quality *(only for smartphone owners)*		9	I always have enough mobile data (such as 4G, 5G) to use my smartphone on-the-go.	-
		10	I always have enough battery to use my smartphone on-the-go.	-
		11	I always have enough storage on my phone for apps I need.	-
Digital skills		12	It is easy for me to learn to use new apps.	Sell et al. (2014)
		13	I can always find the piece of travel information I need online.	Goodman-Deane et al. (2024)
		14	I find the use of travel apps and websites difficult.	Geržinič et al. (2023)
		15	Planning a trip with an app or a website takes me a lot of effort.	Van Acker et al. (2021)

2.3.3 Data collection

The survey was distributed in May and June 2022. We targeted 2,200 respondents in total. As we did not want to overburden respondents using both PT and the car, we split the group in two equal groups, car and PT users. The target profile of each population group was defined based on the Dutch national travel survey, ODiN (Statistics Netherlands, 2024), where age, gender, education level and travel mode frequency were used to define representativeness.

Based on earlier data collected through the MPN, we knew which MPN respondents to target to reach these two representative samples. At the start of the survey, each respondent got a control question to determine whether they fitted in the pre-determined category (car or PT), needed to be directed to the other questionnaire or were no longer part of the target population. A total of 1,740 respondents completed the survey (79% of the target population).

2.3.4 Data preparation

Prior to conducting analyses, we cleaned the data. Any respondent who answered the questionnaire under 3 minutes, or who answered straight lines down in matrix questions four times or more, was deleted. A total of 83 respondents were deleted. Thus, we have a net sample of 1,657 respondents, of which 972 are car users and 685 are PT users. 370 of these individuals also completed the 2018 MPN study (22% of the net sample). Since our sample was no longer fully representative for the targeted populations, we computed weights based on the two target profiles established with the Dutch national travel survey. Our final samples are representative for the populations of car and PT users in the Netherlands (see Appendix A).

2.3.5 Data analysis methods

Our analyses were carried out in SPSS Statistics 29 and consist of three techniques: descriptive analyses, a data reduction technique (see 2.3.5.1) and regression analyses (2.3.5.2). These analyses allow us to describe the process of digital engagement and perceptions of indispensability, and examine links between these aspects and sociodemographic, socioeconomic, and mobility-related variables.

2.3.5.1 Data reduction

We used a data reduction technique to look for relationships among the factors that may be different from the theorised factors. The technique we use for the statements from Table 2.1 is an Exploratory Factor Analysis (EFA). An EFA examines the possibility of a few latent variables accounting for many individual variables (Schreiber, 2021). We will use these latent variables as (in)dependent variables in subsequent regression analyses. Since we cannot run an EFA with missing values, statements on material access were excluded from the analyses and will be analysed descriptively.

We need to assume equidistance between the different levels of the Likert scales, meaning that the ‘No opinion’ and ‘I don’t know’ levels need to be removed to allow for an EFA (Gaskin &

Happell, 2014). All statements had less than 2.2% of responses in the 'No opinion' or 'I don't know' categories, therefore, we decided to keep all statements. Then, we recoded 'No opinion' and 'I don't know' to match the 'Neutral' response. We are aware that this is not ideal but removing the 169 respondents who had answered at least once a 'No opinion' or 'I don't know' would result in too much loss of information; besides, this recoding is common practice (Geržinič et al., 2023).

We performed the EFA employing the Principal Axis Factoring extraction method with oblimin oblique rotation on twelve statements. This type of rotation enables correlation between factors and therefore replicates better human behaviour (Williams et al., 2010). The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for the analysis, KMO=0.837 ('meritorious' according to Kaiser and Rice (1974)), and all KMO values for individual items were greater than 0.67, which is above the acceptable limit of 0.5 (Kaiser & Rice, 1974). We used the scree plot criterion to determine the number of factors, given that the average communality is lower than 0.6 (Field, 2018) (see Appendix B). This leads us to retain 2 factors. The factors are saved using the regression method.

Table 2.2 shows the pattern matrix together with Cronbach's alpha (α), to measure how consistent our post-EFA factors are (Field, 2018). The scales of reverse-phrased statements were reversed to compute Cronbach's alpha. The factors show a good reliability. The post-EFA factors are not exactly in line with those from the survey design phase (Table 2.1), but plausible in terms of interpretation. What we had initially conceptualised as two factors, namely 'Motivation: openness to digital technologies' and 'Digital skills', represents in fact one factor. It seems that digital skills correlate with one's openness to using digital technologies. This makes sense as the internet merges into everyday life (Van Dijk & Van Deursen, 2014). Besides, our statements for 'Motivations: openness to digital technologies' may have been too focused on technical aspects. We name this factor 'Digital skills and experience'. The first factor corresponds to what we had expected.

Table 2.2: Pattern matrix of the Exploratory Factor Analysis (N=1,657).

Item	**1: Perception of indispensability of digital technologies in transport**	**2: Digital skills and experience**
[2] Navigation systems, travel apps and websites are needed in order to travel nowadays.	0.656	
[3] I can always travel where I want to, even if I don't have any digital travel information.	-0.652	
[4] Public information displays like signs along the road or in public transport provide enough information to be able to travel worry-free.	-0.646	
[1] Travelling is more difficult without a smartphone.	0.543	
[12] It is easy for me to learn to use new apps.		0.786
[14] I find the use of travel apps and websites difficult.		-0.772
[15] Planning a trip with an app or a website takes me a lot of effort.		-0.758
[7] It's not a problem for me to use my smartphone, tablet or computer to pay for products or services (like tickets).		0.723
[6] It's not a problem for me to use my smartphone, tablet or computer to book products or services (like tickets).		0.722
[13] I can always find the piece of travel information I need online.		0.684
[8] I avoid the use of digital tools when possible.		-0.592
[5] I like trying out new apps and digital services.		0.441
% of variance	12%	35%
α	0.725	0.877

2.3.5.2 Regression analyses

After descriptively analysing the statements constituting these factors, we conduct Ordinary Least Square (OLS) regression analyses on both factors to uncover variables that explain each of these factors. We use the same set of independent variables for each regression. The variables which were ultimately included in the models were selected through a careful process of hierarchical regression (see Field (2018)) based on their potential importance (based on previous research), their contribution to a better fit of the model, and their low correlation with other variables included in the model:

- *Sociodemographic and socioeconomic variables*: Gender, age, education, and household income,
- *Mobility-related variables*: Car and public transport use frequencies, personal PT smartcard possession (car users can possess a PT smartcard too),
- *Technology-related variables*: Number of types of digital devices owned (between one and three possible: smartphone, tablet and computer or laptop).

Additionally, we conducted binary logistic regression analyses to explain engagement (usage) in relation to the previous concepts (perception of indispensability, digital skills) and other sociodemographic, socioeconomic and mobility-related variables. We conduct two regressions

because we distinguish between car and PT travellers, as the question on the types of travel information sources used was slightly different for both populations. We added a few independent variables compared with the two previous regressions, as justified below:

- *Sociodemographic and socioeconomic variables*: Besides the variables cited above, we control for address density as a low address density is often associated with a more infrequent PT service, and therefore a higher need for travel information.
- *Mobility-related variables*: Not only did we control for car/PT use frequency, but also for the frequency of unfamiliar trips with the car or PT. Unfamiliar trips have been shown to lead to a higher need for travel information (Berggren et al., 2019; Chorus et al., 2007; Farag & Lyons, 2012).
- *Technology-related variables*: We used the two post-EFA access factors here, and controlled for the access to a digital navigation system for car users, as it could be used as a substitute to smartphone-based navigation.

2.4 Results

We present our results starting with the perception of indispensability, followed by the components of digital access (material access, digital skills and experience, and engagement). We first descriptively analyse our statements and questions, then move on to explanatory analyses (where possible) to uncover the role of sociodemographic, socioeconomic, mobility- and technology-related variables in these various aspects of digital access. We also draw comparisons between car and PT users where relevant.

2.4.1 Perceived indispensability of digital technologies in transport

Our results show a clear embeddedness of digital technologies – and the smartphone in particular – in travelling practices. A majority of car and PT users (59%) (strongly) agree with the fact that navigation systems, travel apps and websites are needed to travel nowadays. Almost three quarters of car and PT users (73%) think that travelling is more difficult nowadays without a smartphone (69% of car users, 81% of PT users).

Nevertheless, a majority (57%) of car and PT users state that they can always travel where they want to, even without having personal digital travel information. Therefore, viable alternatives do exist. Still, only 36% agree or strongly agree with the fact that public information displays like signs along the road or in public transport provide enough information to be able to travel worry-free. Therefore, the more traditional communication channels are not deemed sufficient anymore. This could also indicate that people's need for travel information has changed compared to when there was less or no digital travel information available.

Public transport users (fully) agree more often that travelling without a smartphone is more difficult and that digital tools are needed to travel nowadays than car users (Figure 2.1). Nevertheless, on average, the factor 'perception of indispensability of digital technologies' is not statistically different between car and PT users (Mann-Whitney U test, U = 386916, z =

1.843, p = .065), nor is it between individuals who use PT more or just as much as the car and those who do not (U = 282221, z = -1.526, p = .127).

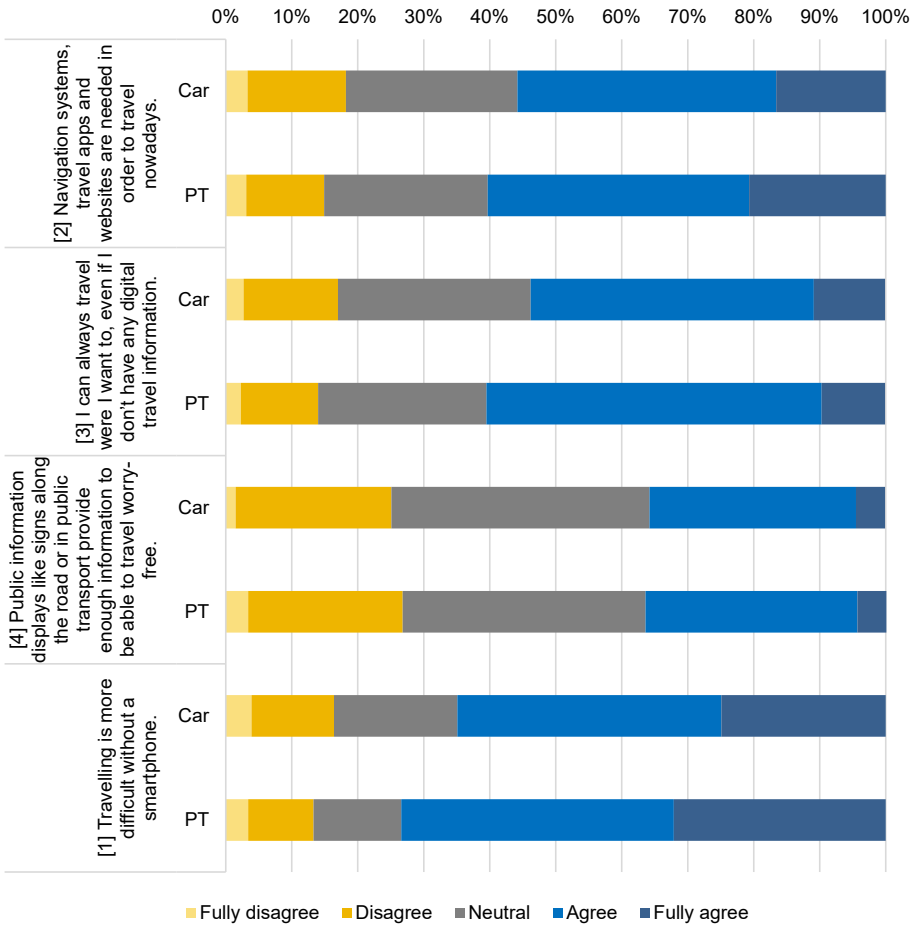

Figure 2.1: Responses to the statements on the perception of indispensability of digital technologies in transport, sorted according to the EFA results and differentiated between car users (N=972) and PT users (N=685).

A linear regression analysis conducted on the factor shows that age significantly predicts the perceived indispensability of digital tools in transport (Table 2.3). Older generations are less likely to perceive digital technologies in transport as indispensable than younger car and PT users. A possible explanation is that older car and PT users have had more experience throughout their life without digital technologies and may therefore be more familiar with alternatives or feel less dependent on personal digital tools. Women are significantly more likely to perceive digital technologies in the context of transport as indispensable. Respondents possessing a personal PT smartcard are more likely to perceive digital technologies in transport as indispensable.

Table 2.3: OLS regression analysis for factor 'Perception of indispensability of digital technologies'. Coefficients statistically significant at 95% level (p < .05) in bold font.

Variable	Levels	**Perception of indispensability of digital technologies**	
		Unst. B	Sig.
Intercept		**-0.328**	**0.010**
Sociodemographic and socioeconomic variables			
Gender	Men	-	-
	Women	**0.153**	**0.000**
Age	18-34	-	-
	35-49	**-0.202**	**0.001**
	50-64	**-0.330**	**0.000**
	65 and older	**-0.443**	**0.000**
Education	Basic, secondary, and basic vocational	-	-
	(Advanced) vocational and college	-0.014	0.825
	University (academic education)	-0.007	0.915
Household income	Below modal	-	-
	Modal	0.031	0.646
	Between modal and twice modal	0.027	0.645
	Twice modal and more	0.068	0.304
	Does not know or want to say	-0.009	0.902
Mobility-related variables			
Car use frequency	4 times a week or more	-	-
	Once to 3 times a week	0.004	0.088
	Between once and 3 times a month	0.046	0.611
	Between once and 11 times a year	0.080	0.782
	Never	0.121	1.118
PT use frequency	Once a week or more	-	-
	Between once and 3 times a month	-0.068	0.399
	Between once and 11 times a year	0.042	0.516
	Never	0.011	0.884
Owning a personal PT smartcard	No	-	-
	Yes	**0.132**	**0.008**
Technology-related variable			
Number of possessed types of technological devices		**0.132**	**0.000**
Model statistics			
N		1657	
R^2		0.06	
Adjusted R^2		0.051	

2.4.2 Material access to a (connected) device

A large majority (98%) of our sample has access to a smartphone. This is more than in the general population: 91% of the Dutch population aged 16 and older had a smartphone in 2022 (Statistics Netherlands (2023b)). While it can be expected with our data collection, our scope also matters: we can expect that people using PT or the car at least six times a year are more used to digital technologies than the average population. Our sample excludes by default people who may not travel much or who have lost their driver's license due to old age for instance.

Looking into the sample of respondents who also participated in the 2018 survey, we see an increase in smartphone ownership. 87.5% had a smartphone back in 2018, against 97% in 2022. We can only speculate on the reasons behind such a change, like a progressive diffusion of smartphones among the so-called laggards and the COVID-19 pandemic that increased the usefulness of smartphone adoption (Sin et al., 2021). Research shows that 90% of Dutch adults used smartphones to access the internet in 2023, against 85% in 2020 (Van Deursen, 2023).

Figure 2.2 shows responses to the three statements on the (perceived) quality of respondents' smartphones, among smartphone owners. 3% of smartphone owners disagreed or strongly disagreed with all three statements. Therefore, in total, at least 5% of Dutch car and PT users either cannot use a smartphone because they do not have one, or run into issues pertaining to mobile data, battery and storage when using it. 19% of smartphone owners (strongly) disagreed with at least one of the three statements. Therefore, at least one in five PT and car users may not be able to always access online travel information.

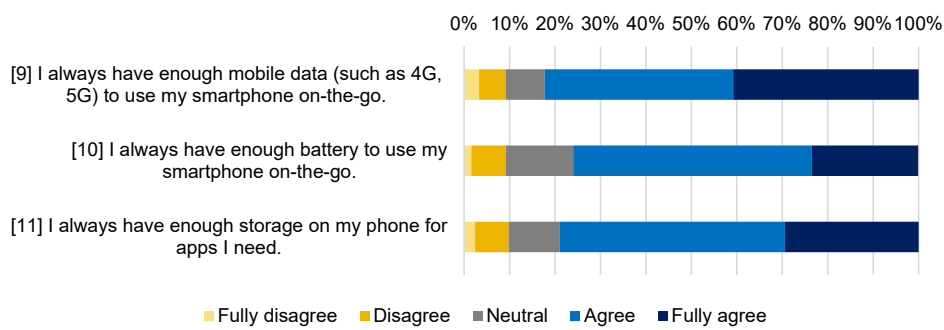

Figure 2.2: Responses to the statements on the perceived quality of the smartphone, by smartphone owners (N=1,629).

2.4.3 Digital skills and experience

Overall, Dutch car and PT users consider themselves to be relatively skilled with digital technologies; see Figure 2.3 for the responses to the statements. Four in five car and PT users do not find the use of travel apps and websites difficult, and planning a trip with these tools does not take a lot of effort for a similar share of car and PT users. Again, four in five car and PT users do not mind booking or paying for products and services like tickets online. Answers

are more split when it comes to liking trying out new apps and digital services: more car and PT users like it than dislike it, but 22% disagree about liking this.

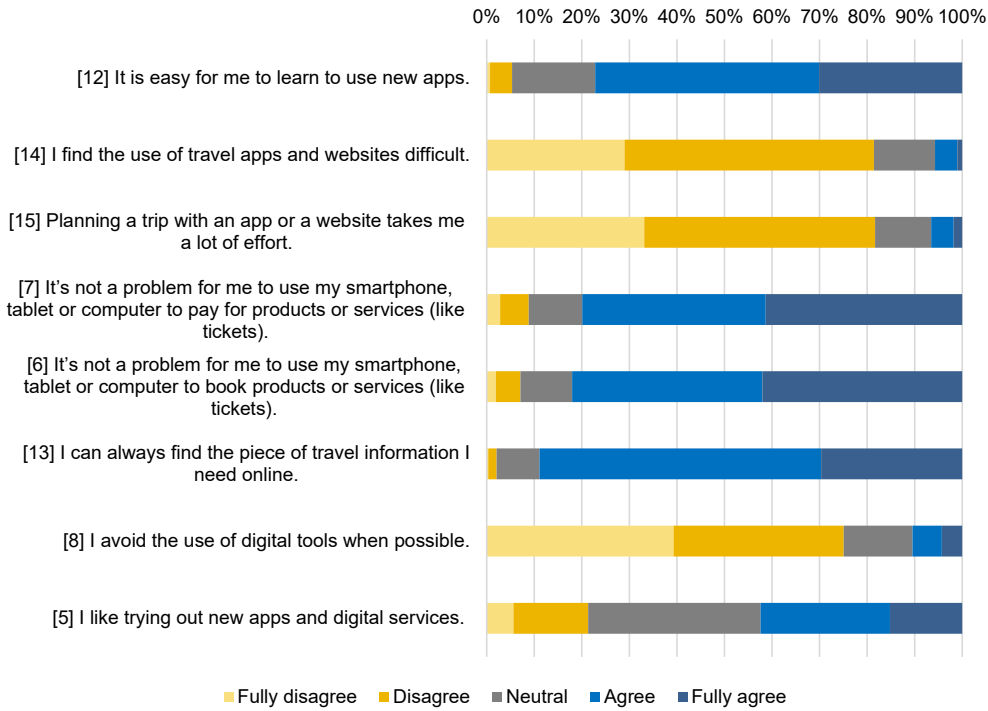

Figure 2.3: Responses to the statements on skills and experience, sorted according to the EFA results (N=1,657).

Booking and paying for products and services online were also part of the 2018 MPN survey, albeit as questions, not statements. Back then, 31% of our 370 respondents had stated that they found it a problem to book products and services online. This share has dropped to 11% in 2022. Similarly, 26% of our 370 respondents had stated that they found it a problem to pay for products and services online. This share has dropped to 10% in 2022. Nevertheless, for almost each statement, between 6% and 10% of car and PT users seem to struggle with various aspects of digital skills applied in transport.

The older the car and PT user, the less likely they are to report high digital skills for travel-related purposes (Table 2.4). Education is also clearly linked with digital skills and experience: car and PT users with an academic, (advanced) vocational or college education are significantly more likely to be digitally skilled than car and PT users with a basic, secondary or basic vocational education. These findings align with research on digital inclusion in general (Van Deursen, 2023), and in transport research too (Durand et al., 2022; Goodman-Deane et al., 2021). Individuals with more than a modal household income are also more likely to report higher digital skills than individuals with a household income below modal. Men are significantly more likely to report higher digital skills for travel-related purposes. As Goswami

and Dutta (2015) showed, women tend to be more anxious about digital technologies than men, reducing their self-effectiveness and increasing perceptions of digital technologies requiring greater effort.

As can be expected, infrequent and non-PT and users as well as infrequent and non-car users usually consider themselves less digitally skilled and experienced to look for travel information than frequent users. People who travel more, likely had to acquire digital skills to look for travel information, if they did not possess them already. Having sufficient digital skills to look for travel information might also foster the possibility to travel. However, we are not able to draw conclusions on the direction of causality.

Table 2.4: OLS regression analysis for factor 'Digital skills and experience'. Coefficients statistically significant at 95% level (p < .05) in bold font.

		Digital skills and experience	
Variable	Levels	Unst. B	Sig.
Intercept		**-0.659**	**0.000**
Sociodemographic and socioeconomic variables			
Gender	Men	-	-
	Women	**-0.114**	**0.007**
Age	18-34	-	-
	35-49	**-0.258**	**0.000**
	50-64	**-0.540**	**0.000**
	65 and older	**-0.921**	**0.000**
Education	Basic, secondary, and basic vocational	-	-
	(Advanced) vocational and college	**0.289**	**0.000**
	University (academic education)	**0.378**	**0.000**
Household income	Below modal	-	-
	Modal	0.121	0.069
	Between modal and twice modal	**0.186**	**0.001**
	Twice modal and more	**0.152**	**0.020**
	Does not know or want to say	-0.003	0.969
Mobility-related variables			
Car use frequency	4 times a week or more	-	-
	Once to 3 times a week	**-0.151**	**0.002**
	Between once and 3 times a month	**-0.185**	**0.013**
	Between once and 11 times a year	-0.143	0.160
	Never	**-0.228**	**0.034**
PT use frequency	Once a week or more	-	-
	Between once and 3 times a month	-0.119	0.135
	Between once and 11 times a year	**-0.151**	**0.019**
	Never	**-0.255**	**0.000**
Owning a personal PT smartcard	No	-	-
	Yes	**0.136**	**0.006**
Technology-related variable			
Number of possessed types of technological devices		**0.342**	**0.000**
Model statistics			
N		1657	
R^2		0.226	
Adjusted R^2		0.217	

'Digital skills and experience' scores for our sample of PT users are significantly higher than for our sample of car users (Mann-Whitney U test, U = 409710, z = 4.040, p < .001). We also find that individuals who use PT more or just as much as the car score significantly higher in terms of digital skills (U = 297444, z = 3.292, p < .001). Note that there is no significant difference in age, educational and income levels between our samples of car and PT users[2].

2.4.4 Engagement with digital technologies to look for travel information

96% of the respondents commonly use some form of personal digital tool to access travel information before or during their trip: a smartphone, a tablet, a laptop/PC/desktop or a navigation system. Looking into the sample of respondents (N=370) who also participated in the 2018 MPN survey, 10% of them stated that they were never using digital travel information in 2018: no navigation system, apps or websites. In 2022, only 4% of this sample did not use digital technologies to access travel information.

Table 2.5 shows sources that respondents employ to access travel information for their car or PT trips. It is worth noting that a majority of car and PT users still rely on public information displays too. Nevertheless, as we saw in section 2.4.1, only a minority of travellers agree that public information displays give sufficient information to be able to travel worry-free.

Table 2.5: Travel information sources used by Dutch car and PT users in 2022 (multiple answers possible)

Travel information source	**Car users (N=972)**	**PT users (N=685)**
Navigation system (built-in or separate device, not a smartphone)	62%	n.a.
Smartphone (such as apps)	74%	90%
Tablet	7%	14%
Desktop, PC or laptop	21%	39%
Family, friends or people I travel with look for digital travel information for me	18%	10%
Public information displays: signs (along the road, at the station…) or maps	68%	56%
Radio with traffic information integrated in the car	30%	n.a.
PT staff or calling 9292 (travel information number)	n.a.	7%
Other travellers (not in my company)	n.a.	2%
No travel information needed (exclusive)	2%	2%

[2] Age: U = 322594, z = 9582, p = .298. Educational levels: X^2 (2, N = 1657) = 4.3, p = .116. Income levels: X^2 (4, N = 1657) = 3.528, p = .474.

Within car users, self-reported digital skills are not significantly lower among those using non-digital alternatives[3]. Within PT users, self-reported digital skills are significantly lower among those using the help of friends, family and staff, but not among those using public information displays[4].

In total, four in five car and PT travellers use their smartphone to look for travel information. We conducted binary logistic regressions to uncover the profiles of those searching for travel information on their smartphone (Table 2.6). As expected from previous analyses, age is a significant predictor of smartphone-based travel information use. For each extra year of age, PT users are 3.7% less likely to use their smartphone to look for travel information and car users 3.6% less likely[5]. PT users with an academic education are three times more likely to use their smartphone to search for travel information than PT users with a basic, secondary or basic vocational education, as are PT users identifying as women (3.5 times more likely than men). Address density does not have a significant effect on smartphone-based travel information use, even when we do not control for other variables.

PT users who never perform unfamiliar PT trips are significantly (89%) less likely to search for travel information on their smartphone than people who perform unfamiliar trips once a month or more. The same applies to car users (70% less likely).

We used our two factors (perception of indispensability and skills) as independent variables here because engagement is the last stage of the process of digital engagement. 'Digital skills and experience' proves to be the most important predictor for both car and PT users. Individuals who are more digitally skilled are more likely to search for travel information via their smartphone. Unsurprisingly, those who perceive digital technologies to be more indispensable are also more likely to look for travel information on their smartphone. As expected, car users with access to a real-time navigation system are less likely to use their smartphone to search for travel information.

The 'digital skills and experience' factor has a mediation effect. Income no longer contributes significantly to explaining smartphone-based travel information use once we control for digital skills and experience (otherwise, PT users from households earning less than modal were found to be significantly less likely to use smartphone-based travel information). The contributions of education level, age and frequency of unfamiliar trips also diminish after controlling for digital skills and experience. Our result is not surprising: digital skills have been repeatedly found to be the strongest predictor for usage, cancelling out the effect of most other variables that were previously statistically significant (Dodel & Hernandez, 2025; Helsper, 2021; Van Deursen et al., 2017). This mediating effect is much less present in the model with car users; the strengths

[3] Family and friends: U = 65597, z = 0.632, p = .528. Public information displays: U = 64130, z = 0.175, p = .861. Radio: U = 102879, z = 1.823, p = .068.

[4] Family and friends: U = 13693.5, z = -4.099, p = .000; mean rank 'no use' = 352.95, mean rank 'use' = 246.46. PT staff: U = 9696, z = -4.230, p = .000; mean rank 'no use' = 351.78, mean rank 'use' = 226.50. Public information displays: U = 61941.5, z = 1.507, p = .132.

[5] When age is entered as a continuous variable, not shown in Table 4; PT: OR (Odds Ratio) = 0.963, CI (Confidence Interval) = 0.943-0.983; car: OR = 0.964, CI = 0.953-0.976.

of the relationships between education level and income also slightly diminish after controlling for digital skills and experience, but they were not significant in the first place anyway.

Age, income and education level appear to be contributing less to explaining the dependent variable once we add the 'perception of indispensability' factor, but the odds ratios only slightly reduce and there is no change in significance levels.

Table 2.6: Binary logistic regression analyses about usage of the smartphone to look for travel information. Coefficients statistically significant at 95% level (p < .05) in bold font.

Variable	Levels	Dependent variables					
		Use of the smartphone to look for travel information among PT users			Use of the smartphone to look for travel information among car users		
		Odds Ratio (OR)	95% Confidence Interval (CI) (lower)	95% CI (upper)	Odds Ratio (OR)	95% CI (lower)	95% CI (upper)
Sociodemographic and -economic variables							
Gender	Men	-	-	-	-	-	-
	Women	**3.517**	**1.692**	**7.311**	0.842	0.586	1.210
Age	18-34	-	-	-	-	-	-
	35-49	0.370	0.106	1.289	0.718	0.393	1.311
	50-64	**0.211**	**0.069**	**0.640**	**0.301**	**0.172**	**0.527**
	65 and older	**0.144**	**0.045**	**0.461**	**0.173**	**0.094**	**0.318**
Education	Basic, secondary and basic vocational	-	-	-	-	-	-
	(Advanced) vocational and college	1.813	0.749	4.389	1.036	0.616	1.742
	University (academic education)	**2.865**	**1.137**	**7.221**	0.748	0.443	1.266
Household income	Below modal	-	-	-	-	-	-
	Modal	3.402	0.978	11.830	1.217	0.689	2.152
	Between modal and twice modal	2.090	0.821	5.319	0.880	0.535	1.448
	Twice modal and more	2.084	0.768	5.650	1.656	0.908	3.021
	Does not know or want to say	**5.745**	**1.396**	**23.646**	0.981	0.531	1.811
Address density	Very high (>2,500 addresses/km^2)	-	-	-	-	-	-
	High (1,500-2,500 addresses/km^2)	0.497	0.221	1.115	0.868	0.539	1.398
	Moderate (1,000-1,500 addresses/km^2)	1.318	0.339	5.128	0.808	0.462	1.414
	Low (<1,000 addresses/km^2)	0.904	0.336	2.436	0.934	0.572	1.525
Mobility-related variables							
Car use frequency	4 times a week or more				-	-	-

	Once to 3 times a week				1.228	0.812	1.857
	Between once and 3 times a month				0.720	0.421	1.232
	Between once and 11 times a year				0.650	0.222	1.904
Frequency of unfamiliar trips with the car	Once a month or more				-	-	-
	Between 6 and 11 times a year				0.770	0.494	1.200
	Between once and 5 times a year				0.754	0.468	1.213
	Never				**0.267**	**0.118**	**0.604**
PT use frequency	Once a week or more	-	-	-			
	Between once and 3 times a month	1.122	0.414	3.045			
	Between once and 11 times a year	1.410	0.561	3.542			
Frequency of unfamiliar trips with PT	Once a month or more	-	-	-			
	Between 6 and 11 times a year	0.715	0.177	2.883			
	Between once and 5 times a year	0.918	0.240	3.505			
	Never	**0.132**	**0.032**	**0.539**			
Technology-related variables							
Perception of indispensability of digital technologies in transport		**1.826**	**1.222**	**2.730**	**1.752**	**1.422**	**2.158**
Digital skills and experience		**3.437**	**2.335**	**5.060**	**2.391**	**1.924**	**2.970**
Access to a real-time navigation system	No				-	-	-
	Yes				**0.281**	**0.157**	**0.505**
Constant		**15.946**			**15.642**		
Model statistics							
N		678			951		
Log-Likelihood		263.845			817.539		
R2 (Cox-Snell)		0.235			0.274		
R2 (Nagelkerke)		0.490			0.399		

2.5 Conclusions, discussion and further research

This study explored the process of digital engagement of car and public transport travellers as well as perceptions around the indispensability of digital technologies in transport. We based our results on a survey conducted in 2022 in the Netherlands among representative samples of PT users (N=685) and car users (N=972). Our questionnaire focused specifically on the smartphone and on digital travel information services. Our approach enables us to establish connections between socioeconomic variables, sociodemographic variables, travel behaviour and digital access. Furthermore, a sub-sample (N=370) had taken part in a survey in 2018 with a few similar or comparable questions/statements, which allowed use to examine evolutions over a period of 4 years.

2.5.1 Differences in four years' time

Between 2018 and 2022, the share of people *not* relying on digital travel information has reduced from 10% to 4%, while smartphone ownership has increased from 88% to 97%. Booking and paying for products and services has also become more common. As such, there is clear evidence of travellers getting more used to digital technologies in just four years' time. The COVID-19 pandemic is likely to have played a role in these changes and there is no guarantee that the same pace will keep on, nor that *everyone* will eventually get used to new digital services. We were not able to compare more aspects of digital access because the dataset used in 2018 had different purposes than our study.

2.5.2 Perception of indispensability of digital technologies

Another noteworthy aspect of our study is our focus on *perceptions around indispensability*. Digital technologies have become embedded in travelling practices: almost three quarters of car and PT users think that travelling is more difficult nowadays without a smartphone. However, viable alternatives do exist and are still used by a majority of car and PT users. PT travellers using the help of friends and family or PT staff to look for travel information are more likely to report lower digital skills. In contrast, traditional communication channels such as signs along the road or in public transport are *not* more likely to be used by car or PT users reporting lower digital skills. Nevertheless, they are not deemed sufficient anymore to travel worry-free.

It would have been highly valuable to compare how current perceptions of indispensability contrast with previous ones. However, we do not have access to such data. Nevertheless, literature from the past decades provides interesting landmarks. For instance, ethnographic research carried out in 2005 among young professionals in London, Tokyo and Los Angeles showed that back then, a mobile phone was 'just' a mobile phone. Most city residents were also carrying things like music players, maps and PT passes in their purses (Ito et al., 2008). Then, the release of the iPhone in 2007 started to change that, such that a few years later, Line et al. (2011, p. 1497) already argued that: 'the development of the mobile phone continues to move it beyond being a device only for phone calls and texts with the offer of connectivity between

people, entertainment, and access to information via mobile internet/GPS on the move across modes. In terms of travelling, the discourses of safety and emergency embedded in the rationale for carrying the phone suggest people travel more confidently (or even carefree)'.

While we only measured perceptions, they contribute to shaping reality. The contemporary expectation for everyone to carry a smartphone and be skilled enough to use it can put those (temporarily) without (the required hardware/skills) at a disadvantage by making them invisible. Our survey did not investigate this aspect, but interviews conducted by Durand et al. (2023c) (Chapter 4 of this dissertation) among individuals at risk of exclusion due to digitalisation in public transport in the Netherlands showed how the perceptions we measured in the present study can play out. Public transport staff sometimes expect travellers to be able to look for travel information independently on their digital devices. Travellers mistakenly believe that non-digital alternatives (to request money back after a disruption, for instance) have completely disappeared given their relative invisibility, meaning that those who would need to access them may not know of their existence.

2.5.3 Disparities in digital engagement

In terms of digital engagement, our survey shows that in 2022, consulting travel information via privately owned digital devices was widespread in the Netherlands. At most 80% of car and PT users relied at least from time to time on their smartphone to look for travel information. However, even respondents of an online panel are not homogenous in their digital access. At least 5% of Dutch car and PT users either cannot use a smartphone because they do not have one, or run into issues pertaining to mobile data, battery and storage when using it. Besides, at least 10% struggle with various aspects of digital skills applied in transport. Older adults, people in households with an income below modal, people with a basic, secondary and basic vocational education level and women are more likely to report lower digital skills and experience in transport, confirming previous findings (Goodman-Deane et al., 2021; Groth, 2019; Zhang et al., 2020). This also confirms that disparities in access to and engagement with digital technologies is patterned along the lines of socioeconomic disparities (Durand et al., 2022).

The same individuals are less likely to use a smartphone for travel information purposes, as also shown by Tao et al. (2024) recently. In fact, our study shows that digital skills are a strong predictor for the use of smartphone-based travel information services and mediate the relationship between this latter variable on the one hand, and income, education level, age and frequency of unfamiliar trips on the other hand. This mediation effect has also been recently demonstrated by Dodel and Hernandez (2025) in a Uruguayan context, and is therefore likely at play in other contexts. Perceptions of indispensability also predict the use of the smartphone, but to a lesser extent than digital skills.

From a transportation equity perspective, the inability to take advantage of technologies may constitute a barrier to accessibility (Bruno et al., 2024; Luz & Portugal, 2021). Accessibility is defined as the potential to reach spatially distributed opportunities (Vecchio & Martens, 2021), and is shaped by the interactions between transport systems, land use and individual attributes (Páez et al., 2012; Van Wee et al., 2013). Indeed, it is not directly the access to and engagement

with digital technologies that matter the most, but it is the opportunities that people may or may not be able to access that matter (Helsper, 2021).

Although car and PT users do not differ significantly in their perception of indispensability of digital technologies, our study reveals other differences between both populations in terms of digital access. In general, car users are less reliant on a smartphone than PT users, as many cars are equipped with a navigation system nowadays (Dicke-Ogenia et al., 2022). Interestingly, a majority of car users in the Netherlands rely on a smartphone *and* a navigation system (built-in or as a separate device). Our survey does not allow us to know if that happens at the same time or not. Furthermore, we see hints that smartphone-based travel information does not require the same (level of) digital skills between PT and car users. Digital skills among PT users are higher than among car users, while these samples do not differ significantly in terms of age and education levels, two key predictors of digital skills (Van Dijk, 2019).

2.5.4 Implications and transferability of the findings

This latter finding has implications for policymakers and researchers in and outside of the Netherlands seeking pathways to decarbonise the passenger transport sector: low digital skills might be a barrier to switching from the car to public transport. One of the limitations of our study consists in the way we measured digital skills (see below), but even a low self-reported (perceived) level of digital skills can be a barrier. This potential barrier is particularly important to take into account as digital transformations in transport services are often depicted as having a central role to play in a shift towards more sustainable mobility patterns (Dutch Ministry of Infrastructure and Water Management, 2019; Groth, 2019; Manders & Klaassen, 2019).

Also, it should not be assumed that everyone can use digital travel information services purely based on a very high smartphone ownership rate. This insight is particularly relevant at a time when many digital services use access to digital travel information as a groundwork (Durand et al., 2018; Lyons et al., 2019; Sochor et al., 2017). Countries, regions or cities where digital technologies are perceived as less indispensable – i.e., where non-digital options are still relatively available – can also find the results from this study insightful. It can help them realise and prevent potentially unintended consequences of a commitment to more digitalisation. We also refer to Durand et al. (2023d) (Chapter 5 of this dissertation) for solutions to foster an inclusive public transport system in the digital era.

2.5.5 Future research recommendations

Future studies should build on this research and address its limitations. Firstly, we encourage researchers to use and refine the statements we have used to capture perceptions of indispensability. It would be interesting to be able to compare results with other countries or places. Obviously, these statements only reflect perceptions, and we recommend pairing them with a good understanding of the context and the extent to which the (transport) system has become/been designed 'digital-by-default' (Yates et al., 2015); this is what makes the qualitative study by Durand et al. (2023c) (Chapter 4 of this dissertation) complementary with the present study.

Secondly, a limitation in our study consists of the way we have measured skills. Self-assessments of skills are known to lead to overrating and underrating (Hargittai, 2009; Van Deursen & Van Dijk, 2010). Nevertheless, they remain one of the most prevalent ways to measure digital skills (Van Deursen et al., 2014). Performance tests could be used in future research (see e.g. Goodman-Deane et al. (2021) and Goodman-Deane et al. (2024) for inspiration), but tasks need to be carefully calibrated.

Thirdly, it is important to note that our regression analyses do not allow us to draw conclusions on the exact causal relationships between variables. For instance, people might be developing skills as they use digital travel information, but we cannot confirm this. An approach via Directed Acyclic Graphs (DAGs) might be helpful to shed light on these aspects.

Chapter 3: Access denied? Digital inequality in transport services

Digitalisation in transport services offers many benefits for travellers. However, not everyone is willing or able to follow the new, more or less formal requirements digitalisation has brought along, as already revealed in Chapter 2. Existing reviews on the intersection between Information and Communication Technologies (ICTs) and mobility cover a range of vantage points, but the perspective of how various levels of engagement with digital technologies affect access and navigation of transport services has not been addressed yet. In communication science, studying disparities in terms of ICT appropriation and their consequences is known as digital inequality research. The study presented in this chapter reviews what digital inequality in the context of transport services consists of and what its consequences are.

After an introduction (section 3.1), section 3.2 introduces the concept of digital inequality and provides a conceptual framework. This framework was already presented in section 1.4, and is used as a lens to read and organise the literature review's results. Then the methodology of the systematic literature review is detailed (3.3). We reviewed 25 papers at the nexus of digitalisation, social exclusion and mobility. The main findings of the review are presented in section 3.4. Finally, future research avenues are suggested (section 3.5), followed by the main conclusions (section 3.6).

This chapter is based on the following article:

Durand, A., Zijlstra, T., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2022). Access denied? Digital inequality in transport services. *Transport Reviews*, *42*(1), 32–57. DOI: 10.1080/01441647.2021.1923584

3.1 Introduction

Over the past decades, the adoption of digital technologies into everyday lives of millions has become a major trend. This is known as digitalisation, or digital transformation, "the integration of multiple technologies into all aspects of daily life that can be digitised" (Gray & Rumpe, 2015, p. 1319), i.e. all aspects that can be converted to a digital form. In his book on smart cities, Townsend (2013) contends that the application of digital technologies – or ICTs (Information and Communication Technologies) – has proliferated in transportation systems, notably in cities, more than in any other urban planning disciplines. In transport services in particular – i.e. public transport (PT) and shared mobility modes such as car sharing and ride sourcing (see Shaheen and Cohen (2020)) – digitalisation is pervasive. From smartcards to real-time multimodal planners and platforms such as Mobility-as-a-Service (MaaS), digitalisation promises to simplify mobility and to provide greater control and choice to travellers over how, when and where they travel (Ferreira et al., 2017; Line et al., 2011). This is notably possible thanks to mobile phones and especially smartphones, which emerged through the convergence of the internet and personal connected devices (Aguiléra, 2019).

Digitalisation in transport is not limited to smartphones though. It is largely relying on the concept of Intelligent Transport Systems (ITS), defined as "the application of modern ICTs to transport systems" (Leviäkangas, 2016, p. 2). Traditional actors in the transport services' industry such as public transport operators have progressively embraced digitalisation to increase the efficiency and the quality of their services while lowering costs (Ampélas, 2001; Davidsson et al., 2016). At the same time, new players operating shared mobility modes have emerged in the transport services' arena (Boutueil, 2019; Wong et al., 2017), leveraging on advances in ICTs to scale up these modes (Shibayama & Emberger, 2020).

Digitalisation is changing the way people get access to and navigate the world of transport services. Yet digital transformations are not simply about converting analogue information into bits and bytes, but bring new organisation structures that change society (Benkler, 2006). Digital transformations do not necessarily retain non-digital elements in the same form, as shown in Table 3.1.

As travellers are increasingly invited to rely on digital technologies in transport services (Aguiléra, 2019; Pangbourne et al., 2018), not being willing or able to engage with digital transformations in such services may create a form of transport disadvantage. According to Schwanen et al. (2015), a lack of basic resources, skills and/or autonomy with regards to travel can result in transport disadvantage. Transport and social disadvantage do not necessarily co-exist (Currie & Delbosc, 2010b), but when they do, there is a risk of transport-related social exclusion (Jeekel, 2018; Lucas, 2012). This is defined by Kenyon et al. (2002) as 'the process by which people are prevented from participating in the economic, political and social life of the community, because of reduced accessibility to opportunities, services and social networks, due in whole or part to insufficient mobility in a society and environment built around the assumption of high mobility.' (pp. 210-211)

Table 3.1 : Selection of digital transformations, with examples (own framework[6]).

Label	From	To	Examples in transport services
Substitution	analogue	digital	Book with public transport schedules → Websites and applications
Liquid digital	digital	digital	Web-based public transport app → Native public transport app (downloaded from an app store)
Co-existence	analogue	analogue (possibly under a modified version) and digital	Static signage (e.g. in public transport) → Dynamic and static signage Paper tickets → Smartcards/e-tickets and paper tickets (with a premium) Monthly offline public transport subscription → Monthly subscription online, with only yearly subscription available offline[7]
Digital only	-	digital	Ride-sourcing applications such as Uber

Furthermore, statistics on internet penetration may mislead professionals and decision-makers who are unfamiliar with the field of digital inequality, i.e. how social groups access ICTs and how various types of engagement with technology lead to offline social (dis)advantages and social exclusion (Chen, 2013). For instance, the Netherlands has the highest internet penetration rate in Europe (98%) and is, with Sweden, the European country with the highest use of mobile internet (87%) (Statistics Netherlands, 2018). Yet in this same country, one in six people aged 16 or older have low numeracy and or literacy skills (Netherlands Court of Audit, 2016). This most likely translates into difficulties navigating the digital world (Van Deursen & Van Dijk, 2014). It can impact access to travel information, with negative outcomes on mobility (Hong et al., 2020). Furthermore, digital inequality may in fact be increasing in the Netherlands (Van Deursen et al., 2015).

Reviews on the intersection between ICTs and mobility have covered a variety of vantage points, from the debate around substitution and complementarity of ICTs and travel, to the experience and use of travel time and space (Aguiléra, 2019; Aguiléra et al., 2012; Andreev et al., 2010; Gössling, 2017; Hjorthol, 2008; Van Wee et al., 2013). However, the perspective of how various levels of engagement with digital technologies in a given context affects access and navigation of transport services – digital inequality in transport services – has not been addressed. This review aims to fill this gap by examining the impacts of digitalisation in transport services on travellers through the lens of digital inequality research. Robinson et al. (2015) argue that such a cross-disciplinary approach is needed, because "digital inequality should not be only the preserve of specialists but should make its way into the work of social scientists concerned with a broad range of outcomes connected to life chances and life trajectories." (p. 570). The three main overarching themes of this review are digitalisation, social exclusion and mobility, with the three main sub-themes being digital inequality,

[6] The terms co-existence, substitution and digital only are used in media research (O'Neill, 2008; Oggolder et al., 2019). We were inspired by Bauman (2006) for the term liquid digital.

[7] Example borrowed from OV Ombudsman (2019).

digitalisation in transport services and transport disadvantage. Their nexus forms the position of this study (Figure 3.1).

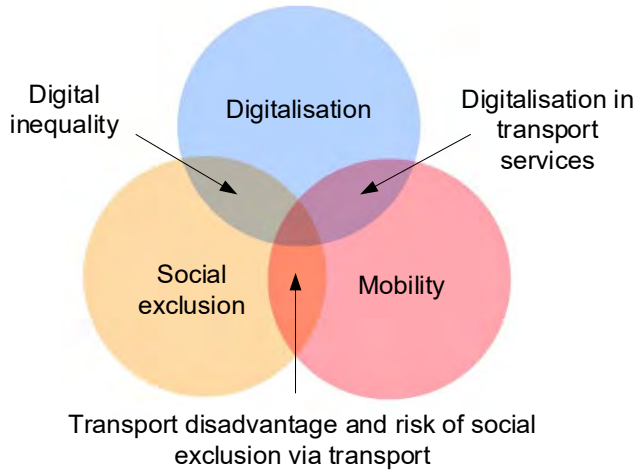

Figure 3.1: Central concepts of this study with the main themes (circles) and sub-themes (own design).

Furthermore, this study echoes to recent calls from scholars to acknowledge and investigate challenges posed by digitalisation in transport and the implications of the digital divide on people's mobility (Banister, 2019; Hensher et al., 2020; Lucas, 2019; Lyons et al., 2018; Macharis & Geurs, 2019). The contribution of this review is threefold:

- It provides a conceptual framework that structures the concept of digital inequality in transport services,
- It synthesises the literature on digital inequality in transport services and
- It highlights gaps in literature and topics where further research efforts are needed.

This study is expected to be useful to researchers who would like to investigate the inclusiveness of transport technologies and systems, yet have little background in communication and media science. This study can also be of value to practitioners who would like to understand the implications of design choices on (potential) travellers and policymakers dealing with a growing political attention to the topic (European Commission, 2020, pp. 99-100).

3.2 Digital inequality

The term digital divide became popular in 1990s in the United States, during a decade of staggering growth of the internet and personal computers (Lupač, 2018). This term reflects an

initially binary conception of digital inequality[8], between those who had access to technologies versus those who had not. Such a difference in terms of physical access has conceptually evolved over the years into motivational access (Van Dijk, 2005) and material access (Van Deursen & Van Dijk, 2018). In the 2000s, as the internet became pervasive in Western countries, some scholars started to question the prevalent idea that physical access to technology would provide all its benefits (Selwyn, 2004). Researchers began to investigate differences in terms of usage (Van Dijk, 2005) and skills (Hargittai, 2001). More recently, the realisation that internet users with similar degrees of access and skills do not reap the same benefits of digital technology marked a shift towards a more comprehensive approach to digital inequality, focused on the consequences of internet (non-)use (Scheerder et al., 2017). Research shows that people with greater offline resources are usually more likely to achieve tangible outcomes from their use of digital technologies and that digital inequality both reinforces and exacerbates social inequality (Scheerder et al., 2019; Van Deursen & Helsper, 2015; Warren, 2007).

Multiple theories and models of digital inequality co-exist. In this study, we sought a framework for understanding digital inequality in transport services, its causes and consequences. A well-known and established theory of digital inequality is the causal and sequential model of digital media access, originally described by Van Dijk (2005). It focuses on the exclusion of individuals due to the integration of ICTs in all aspects of society. Unlike other theories, it is not restrained to a spatial context or a given field (Mariën et al., 2016). For more on digital inequality theories, see Mariën et al. (2016), Pick and Sarkar (2016), Lupač (2018) and Van Dijk (2019).

Van Dijk's model assumes that personal and positional categories lead to different offline resources. These resources influence the extent to which one accesses or appropriates oneself technology, where access consists of four successive factors: motivation, material access, digital skills and usage. These factors are influenced by the characteristics of technologies. This process of access influences participation outcomes and, in turn, offline resources. In spite of the model appearing linear, it can also be read in a circular manner (Van Dijk, 2019). For instance, the fact that gaining skills influences attitudes on technology is included. Van Dijk's model has been tested and validated (Van Deursen et al., 2017; Van Deursen & Van Dijk, 2015).

Transport researchers are usually more acquainted with theories using the acceptance of technology perspective, but these are less informative of digital inequality. For instance, the Theory of Planned Behaviour (Ajzen, 1991) or the Diffusion Of Innovation theory (Rogers, 1962, 2003) only cover the first phases of access to a technology, lack a feedback loop and fail to acknowledge the complexity of adoption of a technology (Lupač, 2018; Selwyn, 2004).

Nevertheless, Van Dijk's digital media access model also has drawbacks. A main criticism is motivation as an entry point. As ICTs are becoming increasingly ubiquitous and profoundly entangled in institutions and daily practices, motivation is no longer the precondition to access technology it used to be (Mariën et al., 2016). Indeed, digital has become the default option

[8] *Digital divide* and *digital inequality* are often used interchangeably (Scheerder, 2019). We favour the latter as it does more justice to the continuum of differences in digital media use and appropriation.

(digital by default) and the individual ability to deal with this digital push may be what increasingly shapes digital inequality, instead of being motivated to use digital technologies. According to Lupač (2018), in order to better investigate digital inequality, it is necessary to assess how indispensable ICTs are in a given context, by examining:

- How embedded these technologies are in everyday routines and in institutions of this field,
- How available non-ICT alternatives are, taking into account that an alternative costing extra resources (time, money, etc.) is not necessarily a real alternative.

This criticism does not invalidate Van Dijk's model though. Research has shown that it is not necessary to have fully completed one factor to be able to access the next one (Van Deursen, 2018). The notion of indispensability is therefore added to the conceptual framework as presented in Figure 3.2.

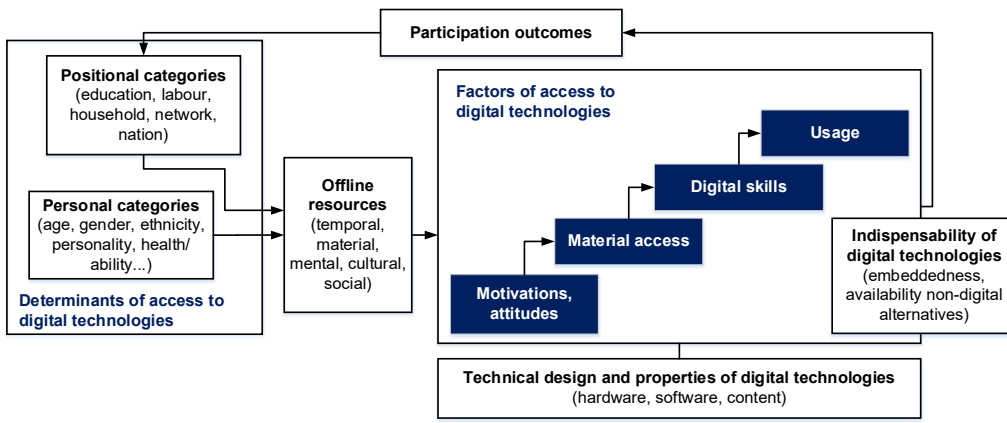

Figure 3.2: Conceptual framework to investigate digital inequality and its consequences (inspired by Van Dijk's model (Van Dijk, 2005, 2019), complemented with the notion of indispensability (Lupač, 2018)).

3.3 Methodology for the literature review

To identify relevant studies, keywords are assigned to each of these themes shown in Figure 3.1 and their overlap, with the goal to identify papers that would stand at the centre of Figure 3.1. The terms in Figure 3.1 were used as starting points to brainstorm relevant keywords among the authors, examining synonyms, historic terms, antonyms and homonyms. Literature was consulted to find terms used interchangeably, such as Lucas et al. (2016) for transport-related social exclusion, Stanley (2011) for social exclusion and Scheerder et al. (2017) for digital inequality. We favoured more general concepts to specific ones, with the expectation that studies that focus on all three main themes will show a certain degree of abstraction. The resulting keywords are displayed in Table 3.2.

Table 3.2: Sets of keywords for the systematic literature review.

Theme	Keywords
Digitalisation	digital* OR technolog* OR analog* OR telematics OR ICT
Mobility	mobilit* OR transport* OR travel* OR trip*
Social exclusion	"social* inclu*" OR "social* exclu*" OR "social participation" OR "social* sustainab*" OR *equit* OR "social engagement"
Digitalisation in transport services	"digitalisation in transport services" OR "smart mobility" OR "intelligent transport*" OR "interconnected mobility" OR "travel* information" OR "integrated mobility" OR "mobility-as-a-service" OR "mobility innovation" OR "transport innovation" OR "mobility app*" OR "transport technolog*"
Transport disadvantage	"social exclusion via transport" OR "inclusive transport*" OR "transport* accessibility" OR "accessible transport*" OR "social* *clusive transport*" OR "transport-related social *clusion" OR "transport* disadvantage" OR "unmet travel need" OR "transport* poverty" OR "mobility poverty" OR "mobility disadvantage" OR "mobility inequalit*" OR "transport* *equalit*" OR "unfulfilled mobility" OR "participation in mobility" OR "latent travel demand" OR "accessibility poverty"
Digital inequality	"digital inequalit*" OR "digital divide" OR "access to ICT" OR "digital skill" OR "digital litera*" OR "e-inclusi*" OR einclusi* OR "digital *clusion" OR "digital ethics" OR "digital gap" OR "internet skill"

The literature search was conducted in English in Scopus. Five queries were created based on the keywords, each query being the intersection (boolean AND) between two or three sets of keywords (Figure 3.3).

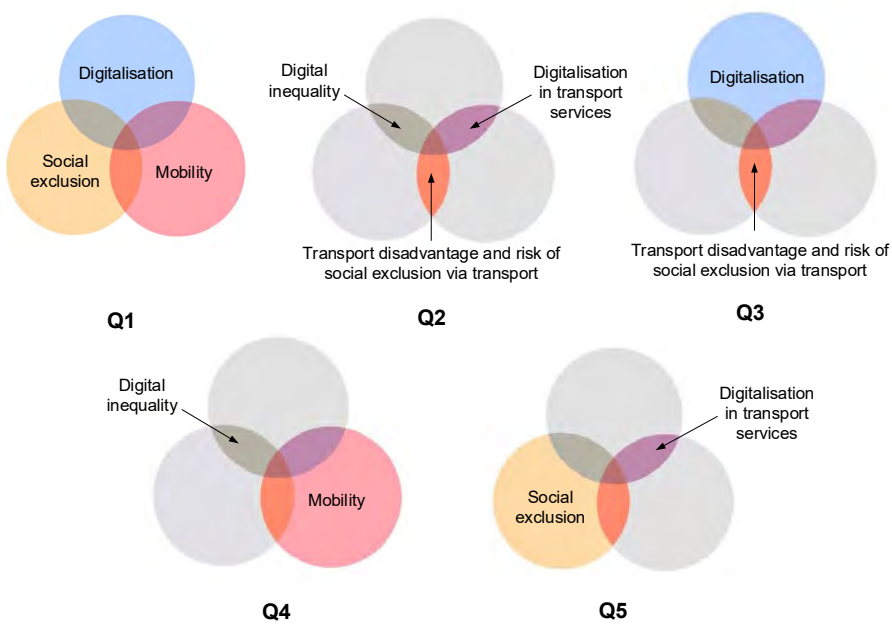

Figure 3.3: Queries for the systematic literature search.

We used the PRISMA guidelines to select papers (Moher et al., 2009) (Figure 3.4). Titles, keywords and abstracts of journal articles, conference proceedings and book chapters were screened using the web application Rayyan (Ouzzani et al., 2016). It allows for a smoother and quicker screening process by providing semi-automation features. Furthermore, forward and backward snowball reviews were conducted on the papers found at the Eligibility step. These techniques, described in Van Wee and Banister (2016), are considered to be useful additions to systematic database searches (Kitchenham & Charters, 2007)[9]. We do not claim that this review be exhaustive because of the theoretical impossibility to reach saturation (O'Reilly & Parker, 2012), choices in keywords and queries as well as the dynamic and multifaceted nature of this topic. We focused on studies with a clearly exposed qualitative or quantitative approach, a distinct link with transport services and chose to leave out essays. After reconciliation, a total of 25 articles were included to be analysed. We then examined each paper through a directed content analysis, a deductive process which implies starting the analysis with a theory as guidance (Hsieh & Shannon, 2005), in our case the framework presented in Figure 3.2. A majority of the selected papers (N=18) are from 2018, 2019 or 2020, demonstrating an increasing interest in this topic.

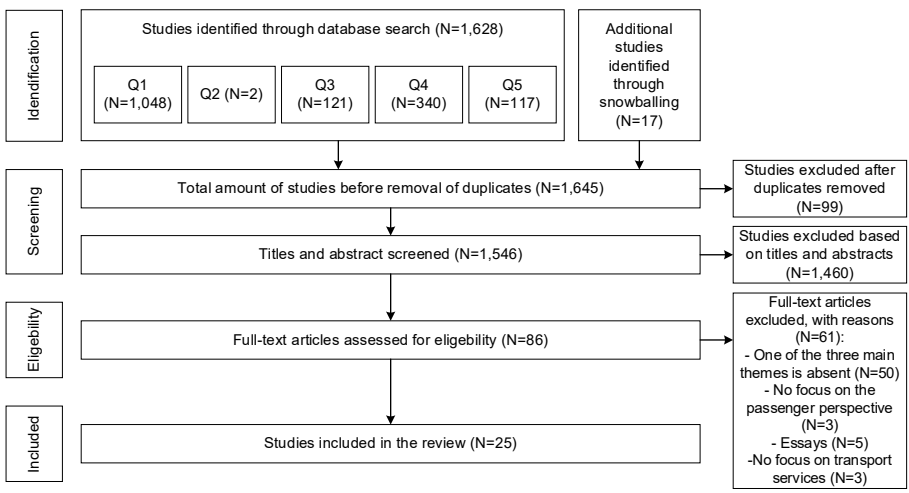

Figure 3.4: PRISMA flowchart for the systematic literature review done in August 2020.

[9] When using snowballing, we found a MIT master thesis (Rizos, 2009) that provides the first mention of a "transit digital divide" (p. 10). Even though it is not strictly speaking peer-reviewed material, we included it because of its pertinence and the fact that it can be used to look back on developments, since it is also one of the oldest selected study.

3.4 Findings

In this section, the conceptual framework (Figure 3.2) is used as a lens to read and organise the literature review's results. As such, this section presents findings from the selected papers (as displayed in Table 3.3), interwoven with relevant results from digital inequality research. This section successively discusses determinants and factors to access ICTs, technical design, indispensability of digital technologies and participation outcomes. Offline resources are not discussed separately. They are discussed together with factors of access (shown in Figure 3.2), as suggested in Van Dijk (2019).

Table 3.3: Details from selected studies, sorted by date.

Year	Author(s)	Location or sources' language	Method	Type of transport service	Determinants of access	Factors of access				Technical design and properties	Indispensability	Negative participation outcomes[10]
						Motivation	Material access	Digital skills	Usage			
2010	Pangbourne, Aditjandra, Nelson	Scotland, U.K.	Focus groups and questionnaires	PT	X	X	X		X	X	X	
2010	Rizos	Canada & U.S.	Literature review & interviews with PT authorities	PT			X	X			X	
2012	Velaga, Beecroft, Nelson, Corsar, Edwards	Scotland, U.K.	Case study	PT & community transport	X		X					X
2013	Kamga, Yazıcı, Singhal	New York, U.S.	Passenger intercept surveys, usage logs and field observations	PT	X		X				X	
2013	Lamont, Kenyon, Lyons	U.K.	Focus groups	PT	X	X				X		X
2016	Sochor, Nikitas	U.K., Sweden	Semi-structured	PT	X	X						X

[10] We discuss both positive and negative outcomes in this paper. Nevertheless, due to our selection process, papers included in this review tend to focus more on detrimental outcomes, with positive outcomes frequently mentioned but more superficially addressed.

			interviews, focus groups, postal surveys									
2017	Snellen, De Hollander	The Netherlands	Expert interviews	PT, shared mobility, autonomous shuttles		X		X		X	X	
2018	Gebresselassie, Sanchez	U.S.	Systematic literature review and analysis of transport apps	PT, shared mobility	X					X	X	X
2018	Jin, Kong, Wu, Sui	Literature in English	Systematic literature review	Ride sourcing	X	X	X					X
2018	Shirgaokar	Canada	Focus groups, interviews	Ride sourcing	X	X				X		
2018	Vecchio, Tricarico	Literature in English and Italian	Literature review	PT, shared mobility		X	X	X		X	X	
2018	Wang, Mu	Atlanta, U.S.	Analysis of Uber data	Ride sourcing						X		
2019	Bertolaccini, Hickman	Queensland, Australia	Online surveys	PT, ride sourcing, community transport	X	X	X		X		X	X
2019	Bigby, Johnson, O'Halloran, Douglas, West, Bould	Sydney, Australia	Interviews, focus groups	Train	X		X				X	

2019	Golub, Satterfield, Serritella, Singh, Phillips	Portland, U.S.	Case study with focus groups, online and in-person survey	Shared mobility, autonomous shuttles	X	X	X				X	X
2019	Groth	Germany	In-person or postal survey	PT, shared mobility	X	X	X				X	X
2019	Harvey, Guo, Edwards	U.K.	Citizen and expert interviews	PT, shared mobility	X	X	X			X	X	
2019	Malik, Wahaj	Pakistan	Semi-structured interviews	Ride sourcing	X						X	
2019	Musselwhite	U.K.	Focus groups	PT, shared mobility, autonomous shuttles	X	X					X	
2019	Pangbourne, Mladenović, Stead, Milakis	Mostly documents in English	Documentary analysis and case study	PT, shared mobility	X						X	X
2019	Sabie, Ahmed	Canada	Interviews	Public transport	X	X						
2020	Aberle	Hamburg, Germany	GIS analysis	On-demand bus						X		X
2020	Sherriff, Adams, Blazejewski, Davies, Kamerāde	Manchester, U.K.	Online surveys, interviews	Dockless bike sharing	X	X	X			X		

2020	Sourbati, Behrendt	U.K.	Case study	PT, shared mobility, community transport						X		
2020	Zhang, Zhao & Qiao	Ürümqi & Wuhan, China	Face-to-face surveys	PT, shared mobility	X	X		X	X		X	X
Totals					19	15	12	4	3	11	15	11

3.4.1 Determinants of digital inequality in transport services

3.4.1.1 Main personal and positional categories of vulnerable groups

According to literature, age, income and education levels, ethnicity, gender and the type of region play a role in digital exclusion from transport services.

Age. Multiple studies agree on the fact that older adults in particular are vulnerable to digitalisation in transport services, providing three main interlinked reasons. First, they are more at risk of being transport disadvantaged, especially for those who are no longer able to drive, as staying active in later life is linked to quality of life (Musselwhite, 2019; Pangbourne et al., 2010). Older women who used to be driven by their husband and people who stopped driving are particularly at risk of having their mobility needs unmet (Bertolaccini & Hickman, 2019; Shirgaokar, 2018). Second, older adults are usually more likely to be reluctant to engage with technology in general (Harvey et al., 2019; Pangbourne, 2018), which is also verified in transport services (Sherriff et al., 2020). This may come from the fact that they have managed their mobility during their whole life without these technologies. It could also be that they adopt technology at a slower pace. Third, as ageing is a natural maturation process, a progressive reduction in cognitive abilities such as processing speeds and a decline in other psychological mechanisms mean that coping with new technologies can be difficult (Harvey et al., 2019). For instance, Pangbourne et al. (2010) highlight that studies show an age-related decrease and difficulty in using public information kiosks and ticket machines.

Income and *education levels* often go hand in hand. People with lower incomes are vulnerable to digitalisation in transport services because they cannot afford credit cards and even possibly bank accounts, they are less likely to have and use internet at home and at work and they are more likely to have to cancel or reduce data plans (Golub et al., 2019; Sherriff et al., 2020). Before even considering subscribing to relatively expensive offers from mobility services (Pangbourne et al., 2020), entering the ecosystem of digitally-based transport services is problematic. This was also verified by Groth (2019): people with low income and low education levels are more likely to have fewer transport options to choose from, and to have no smartphone.

Ethnicity. According to Golub et al. (2019), Sabie and Ahmed (2019) and Zhang et al. (2020), ethnicity is also an important factor. For instance, Golub et al. (2019) found that respondents of colour in Portland (U.S.) were more likely to rely on cash payment in public transport, and less likely to use cashless methods. Together with lower income groups, they were also more likely than average to have cancelled their cell phone service because of costs. The study of Zhang et al. (2020) reveals that minority groups are particularly vulnerable to digitalisation in transport services due to their lack of digital skills. Van Dijk (2019) notes though that differences among ethnic and minority groups are in fact “related more to economic deprivation, discrimination and cultural preferences than to race” (p. 42).

Gender. In China, Zhang et al. (2020) found that women were more likely to be vulnerable to digitalisation in transport services. This is a relatively common observation in developing countries and/or countries where women are less emancipated (Van Dijk, 2019). This might

explain why this determinant has not been mentioned by the other studies investigated in this study, as most focused on an European, North-American or Australian setting.

Type of region. Rural communities are presumably more vulnerable to digitalisation in transport services because of a lack of adequate ICT infrastructure, which can subsequently hinder the possibility to access real-time information for instance (Malik & Wahaj, 2019; Velaga et al., 2012).

3.4.1.2 Some caveats

First, it is unlikely that there is homogeneity within and among all these groups, for instance between people aged 65-75 and people aged 75 and older (Bertolaccini & Hickman, 2019). Second, there is a multiplicity of determinants playing a role in access to digital technologies. For instance, learning disabilities, low literacy/numeracy levels and communication impairments make navigating the digital world of transport services difficult (Bigby et al., 2019; Malik & Wahaj, 2019). In addition, people who are experiencing issues with digitalisation in transport services may already have had issues when everything was analogue, making low access to ICTs another layer on top of existing layers of transport disadvantage (Bigby et al., 2019; Lamont et al., 2013). Third, we note that a person might be at a disadvantage to access or use a certain type of service – for instance, online ticketing – while being able to reap the benefits of another type of service – for instance, looking for travel information.

3.4.2 Factors of access to digital technologies in transport services

This section successively addresses the four factors of access to digital technologies, being motivations, material access, digital skills and usage.

3.4.2.1 Motivations, attitudes

Multiple selected studies mention the importance of attitudes and motivation as an entry point to engage with digital technologies in transport services, notably Groth (2019). He defines the 'mental preconditions to use modern ICTs' (p. 63) with five categories: autonomy, excitement, flexibility, privacy and status. Literature reveals two main reasons for non-use of digital technologies applied in transport services that partly overlap with Groth's categories:

- The first main reason mentioned is a *rejection of the technology due to a perceived lack of trust, security, privacy and reliability*. Fears of data misuse with internet banking, scams, identity theft, phishing and fraud can dissuade people from paying online for their transport subscription or for a ride (Harvey et al., 2019; Pangbourne, 2018). This is particularly the case for older adults and people with lower incomes (Musselwhite, 2019; Shirgaokar, 2018). In general, people need to feel safe and in control, which is perceived to go against a heavy reliance on technology (Pangbourne et al., 2010; Shirgaokar, 2018). Privacy is a growing concern because of the ability of digital technologies in transport to track people's journeys (Groth, 2019; Vecchio & Tricarico, 2018). Data leakages at companies may further accentuate this mistrust (Jin et al., 2018).

- The second main reason for non-use of digital technologies in transport services is that people *do not want the technology, either because they have a lack of interest in it or because they do not find it useful*. Not everybody knows of the existence of or sees the relevance of technologies such as smartphones, meaning that their application and potential added value remain invisible (Pangbourne et al., 2010).

These two main reasons are linked with other reasons, such as a lack of money, a perceived lack of (ability to acquire) skills and time and the fear to appear foolish (Sochor & Nikitas, 2016). Furthermore, people's social network is deemed an important resource to foster motivation to use digital technologies in transport services (Harvey et al., 2019; Sabie & Ahmed, 2019).

3.4.2.2 Material access

The smartphone has taken an increasingly important role in transport services (Gebresselassie & Sanchez, 2018), owing to the wide range of possibilities it offers to users and operators. Nevertheless, while applications are often free or come at a nominal cost, smartphones (computers, tablets…) are not free and nor is the data plan, the stable internet connection or the printer for the e-ticket (Golub et al., 2019; Rizos, 2010). The older adults interviewed by Harvey et al. (2019), though coming from a panel of 'largely well-educated, financially comfortable' people (p. 176), mention the costs of technology as a barrier. The researchers found that the quick obsolescence of devices and the need to replace them regularly annoys people, who feel pushed to adopt newer forms of digital technology. Concretely in transport services, this could mean that some people might be unwilling to purchase a new smartphone so that transport apps can function well on it. Besides, owning a smartphone is not enough: one needs to ensure that there is enough battery, that it is being repaired when broken and that the operating system is up-to-date and able to support applications running on it (Golub et al., 2019; Groth, 2019).

3.4.2.3 Digital skills

The need for digital skills in transport services tends to be underestimated. Public transport authorities interviewed by Rizos (2010) predicted that smartphone penetration and further developments in transport technologies would make analogue channels obsolete. There was the belief that the digitally disadvantaged would catch up as technology would become cheaper. This reasoning reveals a fundamental misunderstanding of digital inequality: having material access to the physical technology does not mean that people benefit from what the technology has to offer them (Zhang et al., 2020).

Online travel information makes information that was previously unavailable or hard to find, easier to access and potentially understand (Bigby et al., 2019; Gebresselassie & Sanchez, 2018). As such, it can contribute to a decrease in the resistance to use transport services, especially for inexperienced users. Yet Zhang et al. (2020) found that lacking knowledge on how to operate a smartphone and use location-based services was associated with a higher likelihood to have a restricted access to travel information. It is important to distinguish between medium- and content-related skills, both of which are dynamically evolving with technology and people (Pangbourne et al., 2010; Vecchio & Tricarico, 2018):

- Medium-related skills are related to operating a digital medium, like a turning on and off a smartphone and understanding what a browser is. They are necessary to successfully develop content-related skills (Van Dijk & Van Deursen, 2014).
- With the proliferation and fragmentation of online information, knowing how to use location-based services, query travel information, assess its reliability and act upon it become important (Vecchio & Tricarico, 2018). Such content-related skills are called information and strategic skills, related to searching, finding, processing and critically assessing information (Van Dijk & Van Deursen, 2014). The difficulty in selecting the right piece of travel information can result in people abandoning their journey (Lamont et al., 2013). Furthermore, skills related to privacy management also become important. In that sense, having some privacy concern can be constructive, as it actively pushes people to take action to protect their data (Zhang et al., 2020).

3.4.2.4 Usage

Usage follows from motivation, material access and skills (Van Dijk, 2005). People whose material access or digital skills are limited use travel apps less and with less variety, even among public transport captives (Bertolaccini & Hickman, 2019; Zhang et al., 2020). Furthermore, Bertolaccini and Hickman (2019) noted that 84% of the older adults they surveyed use their tablet, laptop or PC at an equal or higher frequency than their smartphone to access travel and navigation information. In spite of new transport technologies often revolving around apps, this shows that the home and seated use of online travel information still has considerable value to some groups. Bertolaccini and Hickman (2019) and Pangbourne et al. (2010) underline that transport planners should not expect everyone to be able to access information on-the-go.

3.4.3 Technical characteristics of digital technologies in transport services

Literature highlights two pathways in which the technical characteristics of digital technologies can impact transport services people have access to: through usability and through an increasingly heavy reliance on data and algorithms.

3.4.3.1 Usability: the importance of hardware and software design

Usability is an important characteristic of contemporary digital media, affecting the possibility of developing digital skills and therefore to derive benefits from technology. Drawing from Shneiderman (1980) and Nielsen (1994), Van Dijk (2019) defines usability as the combination of intuitiveness and: 'learnability (the ease of accomplishing a basic task), efficiency (how quickly this task may be performed), memorability (remembering how to carry out a certain task), correction of errors (how many errors are made and how they can be recovered) and satisfaction (the pleasure of using the tool)' (p. 75).

Selected literature sheds light on issues related to usability that specific groups encounter, such as older adults and people with an impairment. For instance, older adults mention small keypads and pictograms as problematic (Pangbourne et al., 2010), while people with language barriers

report issues pertaining to having too much information displayed on a single screen and a lack of forgivingness for spelling mistakes in navigation apps (Lamont et al., 2013). Both hardware and software can create barriers. As digital technologies increasingly allow for customisation, these aspects tend to get more recognition – at least on the software side (Gebresselassie & Sanchez, 2018). However, increasing usability among vulnerable groups is not simply about making amendments to existing systems, but more about organising technology around the way people process information to keep them in control and aware (Harvey et al., 2019; Lamont et al., 2013).

3.4.3.2 Algorithm-based and data-driven decision-making

A second, more covert and indirect way in which technology characteristics can contribute to digital exclusion from transport services is through algorithms and an intense reliance on digitally collected data. Data collected through sensors, smart cards, applications and surveys increasingly shape and drive transport services and policy decisions (Sourbati & Behrendt, 2020). However, people who are not present in data are invisible to planners as well as (self-learning) algorithms that assist the dispatching of transport services. Drawing on Kwan (2016), Vecchio and Tricarico (2018) argue that 'algorithms offer partial representations of urban phenomena that are prone to omissions and exclusions' (p. 6), with the semblance of objectivity[11]. There is a risk that commercial initiatives that develop their transport services primarily based on digital infrastructure (such as ride-sourcing platforms) shun certain neighbourhoods because they are not profitable enough.

If left unsupervised, algorithms may exclude – intentionally or not – groups of people that are already disadvantaged in some way (Snellen & de Hollander, 2017). Nevertheless, evidence on that point is still contradictory. Wang and Mu (2018) found that there was no evidence yet that Uber was related to an aggravation or an alleviation of the existing socio-spatial disparities in Atlanta. In contrast, Aberle (2020) uncovered that peripheral districts do not seem to hold sufficient potential to profitably run ride-pooling services in Hamburg. Only one out of the four analysed on-demand bus services was found to deliver utility for low-income and socially excluded groups, while the three others were mainly operating in affluent districts. The difference was that that first scheme had been obliged by public administration to operate in a more remote area. Still, selected studies agree on the fact that digital technologies can directly impact the physical offer of transport services available to a specific person, potentially creating a spatial selectivity. This selectivity can dynamically evolve as the provider wishes through geofencing, as Sherriff et al. (2020) shows with dockless bike sharing in Manchester. For more on the socio-spatial equity of shared mobility, see the notion of splintering urbanism (Graham & Marvin, 2001) as put forward in the review by Chen et al. (2020) on dockless bikes.

[11] See Bijker and Law (1992) about biases from people – typically, dominant groups – shaping technologies.

3.4.4 Indispensability of digital technologies in transport services

The indispensability of ICTs can be found at different levels in public transport and shared mobility, as explained below.

3.4.4.1 Public transport: increasingly digital by default, with concerns

In the case of public transport, literature highlights how travellers are increasingly expected to conduct tasks via digital channels by default, to have their own means to buy tickets or look for travel information (Rizos, 2010; Snellen & de Hollander, 2017). Although digital and analogue media may still often coexist, the latter may take a modified form, requiring more money (a premium), more energy and/or more time (see Table 3.1), potentially discouraging its use (Snellen & de Hollander, 2017). Furthermore, while digital technologies may be helping staff to better assist travellers, literature notes that these technologies are also substituting for employees. This is a cause for concern among groups that feel vulnerable (Musselwhite, 2019), particularly when it comes to responding to irregularities or last-minute changes (Bigby et al., 2019). A station kiosk can be an alternative to staff and still relatively low-tech; however, it may still present challenges for those who have little experience with computers and smartphones (Kamga et al., 2013). Overall, Sourbati and Behrendt (2020), Pangbourne et al. (2010) and Jin et al. (2018) caution that a digital push is particularly questionable in the case of a public service.

3.4.4.2 Shared mobility: more than digital by default, digital only

In shared mobility such as ride sourcing, car and bike sharing, not only is digital the default option, it is also nowadays frequently the only option (Pangbourne et al., 2020). Without digital technologies such as smartphones and/or credit cards, there is often no way to unlock these digitally-based transport modes (Groth, 2019; Vecchio & Tricarico, 2018). Mobility-as-a-Service (MaaS) is also premised on such technology use (Pangbourne et al., 2020).

Furthermore, Golub et al. (2019) mention the 'banking divide' as a significant barrier to access these services, affecting low-income and minority households especially. Such a divide is arguably more of a problem in developing economies (Pangbourne et al., 2020), although the ban on cash in buses in countries such as the UK and the Netherlands also raises questions.

One may argue that commercial shared mobility providers can target the population they want, namely people with smartphones and bank accounts. However, if these modes are to be further scaled up with the objective to encourage more environmentally sustainable travel practices as often put forward, the question of exclusion due to digital only becomes more significant (Pangbourne et al., 2020). This is especially true as the production of multimodal travel behaviour – a central element of the sustainable modal shift suggestion – is conditioned by access to digital technologies (Groth, 2019).

3.4.5 Participation outcomes

Almost all selected studies mention positive outcomes linked to digitalisation in transport services. Real-time information has brought clear benefits to travellers (Velaga et al., 2012).

Personalised assistance allowed through ICT advances, such as features that address impairment and language barriers, can support more inclusiveness and participation (Bigby et al., 2019; Pangbourne et al., 2010). Furthermore, shared mobility modes are often presented as opportunities to meet the needs of groups with a low range of transport options available, because they could safeguard and afford mobility without the need for private vehicles (Golub et al., 2019; Malik & Wahaj, 2019).

As such, digitalisation can be part of the solution to transport disadvantage, but it can also be part of the problem (Lamont et al., 2013). Gebresselassie and Sanchez (2018) warn that '[a lack of] access to emerging technologies affects the same demographics whose transport disadvantage could be alleviated using advancement in ICTs' (p. 8). In Australia, Bertolaccini and Hickman (2019) found that many older non-drivers do not own smartphones and make fewer trips to friends and family, even with a sample biased towards urbanised areas. This led them to conclude that transport services requiring smartphone apps use would almost certainly exclude many older Australians and not solve the transport-related social exclusion they face. A correlation between mode options and smartphone distribution has also been observed by Groth (2019).

Similarly to recent conclusions in digital inequality research (Van Dijk, 2019), literature acknowledges that digital inequality in transport services is likely to follow and possibly reinforce patterns of social inequality (Groth, 2019; Pangbourne et al., 2020; Zhang et al., 2020). Furthermore, there are often economic and commercial stakes in the introduction of ICTs in transport services. When left unchecked, these stakes may fuel a technological push that downplays consequences on society (Pangbourne et al., 2020; Sochor & Nikitas, 2016). Through a critical analysis of the MaaS rhetoric (where shared mobility modes are to play a central role), Pangbourne et al. (2020) caution that MaaS's 'promise of freedom cannot be delivered with respect to well-being and inclusion' (p. 44).

Not only is the risk for exclusion pointed out in literature, but also the risk for (further) polarisation (Jin et al., 2018) and a "technological gentrification" of transport services (Pangbourne et al., 2020, p. 43). Yet cumulative advantage is a mechanism for inequality (DiMaggio & Garip, 2012; DiPrete & Eirich, 2006). In network behaviour theory, this is known as the flip side of Metcalfe's law (Tongia & Wilson, 2011) and was applied in transport by Dupuy (1999, 2011) to explain automobile dependency. The reasoning as applied in the case of digitalisation in transport services is explained in Figure 3.5. What is first considered to be a relative disadvantage can turn into an absolute disadvantage and exclusion from the network. In that sense, digital inequality in transport services is not just about exclusionary effects but also about a potentially changing accessibility distribution among social groups.

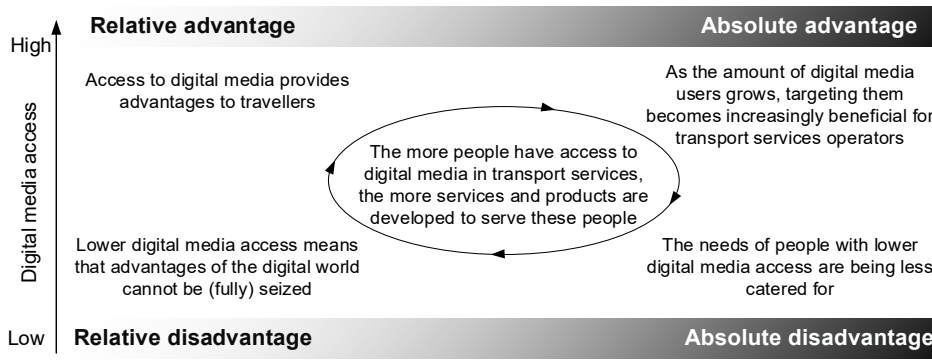

Figure 3.5: Schematic of the relationship between relative and absolute (dis)advantage and digitalisation in transport services (own design).

3.5 Future research directions

Given the relatively nascent state of research on digital inequality in transport services, much remains to be understood. It is our hope that our cross-disciplinary perspective will inspire other researchers to investigate this topic from different angles. We present here a few main research avenues relevant to scholars and professionals interested in the inclusiveness of digital transformations in transport services.

3.5.1 Mechanisms of digital inequality in transport services

More empirical evidence on the determinants and factors of access to technology (and how they relate to each other) is needed to better understand the mechanisms of digital inequality in transport services, i.e. who is impacted and in which way. Because studying impacts on mobility in general is too broad, focusing on one particular pattern could be useful. This is what Zhang et al. (2020) did, by investigating the pattern of obtaining transport information.

In terms of determinants, further research could confirm the dimensions of vulnerability as presented in this study and uncover additional ones, inspired from digital inequality research (Scheerder et al., 2017). Distinguishing between various groups could allow to better identify specific barriers and needs.

In terms of factors, ICT usage and digital skills required in transport services and how they are linked to determinants are particularly underexplored. More research is needed, as these two factors are deemed even more important than determinants in shaping outcomes of digital technologies' use (Van Deursen & Helsper, 2018). Investigating the intricate relationships that link factors together (with determinants) could also prove valuable.

Overall, we encourage researchers to refine the framework suggested in this study, thereby tailoring it better to the specific context of transportation. This implies a closer look at the role

of spatial determinants. For instance, not being able to access travel information will not have the same outcome in a high-frequency metro system as in a low-frequency rural bus service.

3.5.2 Relative (dis)advantage

Relative (dis)advantage is highly contextual. We encourage researchers to develop a local understanding of what indispensability means. Here, we see two complementary paths.

The first one would require a careful examination of how relatively vulnerable populations cope with the pervasiveness of digitalisation in transport services. People may have different priorities, meaning that indispensability may vary individually. Here, the Capability Approach would offer a suitable framework, as it explicitly recognises the diversity of human needs and preferences (Sen, 2009). One of the selected papers in this review, Sherriff et al. (2020), applied this approach. It can be used to investigate how mobility contributes or not to the achievement of individual freedoms and aspirations (see e.g. Ryan et al. (2019) and Nordbakke (2013)), but it can also be used to consider issues of transport justice (see e.g. Vecchio (2020)). Additionally, the concept of motility which includes notions of access, skills and appropriation (Kaufmann et al., 2004), may be useful to advance our understanding of how digitalisation in transport services interacts with the potential to be mobile. Besides these two approaches, a perspective of distributive justice could also be helpful to determine the extent to which access to digital tools in transport services matters in terms of accessibility (Pereira et al., 2017).

The second path would focus on the tangible benefits that people reap from having access to digital technologies to plan and manage their daily mobility. Who is able to reap such benefits, why, in which context and how? How do they shape the meaning of indispensability? Scholars interested in this avenue could get inspiration from third-level digital divide research (Van Deursen & Helsper, 2015). In any case, such research would require an exploration that goes further than simply ‘ICTs in transport services provide convenience’.

3.5.3 The contribution of digital inequality to transport disadvantage and transport-related social exclusion

Although some literature acknowledges the association between digital inequality/exclusion and transport disadvantage/transport-related social exclusion, empirical evidence remains limited on the contribution of the former to the latter. Is digital inequality in transport services creating a new form of transport disadvantage, thereby contributing to exclusionary processes on its own, or is it adding to or even changing existing disadvantages?

Furthermore, scholars could seize digital transformations occurring in transport systems as opportunities for investigation, such as Pritchard et al. (2015) with the ban on cash in London buses. As the COVID-19 crisis intensifies digitalisation in all fields (Robinson et al., 2020), examining these processes of digital transformation in transport services and their potentially exclusionary effects would be valuable.

3.5.4 Solutions to mitigate or prevent digital inequality in transport services

Identifying and examining strategies to mitigate or prevent digital inequality in transport services is important to bring this issue to policymakers' or practitioners' attention. No clear overview and discussion on this exists yet. For instance, although training is frequently mentioned by the selected papers, the different ways to teach people, their pros, cons and most importantly, the underpinnings of such an educational perspective, are seldom discussed.

Mitigating digital inequalities in transport services also requires a broader reflection on technology governance, as initiated by Pangbourne et al. (2020). Here, research could focus on power imbalances (Royakkers et al., 2018), how to be responsive to changing values and circumstances (De Reuver et al., 2020), the anticipation of technological impacts and processes of inclusion in technology governance (see e.g. Stilgoe et al. (2013) for methods). The latter point on inclusion echoes to the call for a shift from a state- to a more society-centric way to achieve transportation equity and justice (Karner et al., 2020; Sheller, 2018). The approach of Sourbati and Behrendt (2020), linking data justice with Sheller's mobility justice, could be an interesting avenue to explore.

3.6 Conclusions

This study investigated digital inequality in transport services by examining the impacts of digitalisation in transport services on (potential) travellers through the lens of digital inequality research. Motivated by a lack of attention to this particular perspective in the research on ICT and mobility, we searched for relevant literature and reviewed twenty-five papers addressing digital exclusion from transport services. Our goal was to shed light on what digital inequality in the context of transport services consists of and what its implications are. Literature on this topic is in a nascent state, but interest has grown sharply over the past two years. In general, reviewed studies focus on a few aspects of digital inequality and do not necessarily have in mind the bigger picture, or at least they do not make it explicit. This is where the conceptual framework presented in this study, embedded in our cross-disciplinary approach, adds value. In turn, this framework allowed us to synthesise the main findings on digital inequality in transport services and subsequently to list topics where further research efforts are needed.

A main conclusion is that digital inequality, or the digital divide, is a multi-layered process. In both public transport and shared mobility, the smartphone has taken a central role within a decade, but having a smartphone does not mean that one can derive all of its benefits. The reviewed literature acknowledges this, notably by focusing on the nuances of material access as well as motivations and attitudes. The importance of digital skills and a diversity and frequency of usage are recognised but empirical research on these factors remains scarce. Overall, literature acknowledges that being unable or not willing to access, successfully and efficiently operate and use digital technologies in transport services may result in a disadvantage to use such services.

Deriving beneficial outcomes from digital technology involves more than personal resources. The socio-technical context in which individuals operate, such as characteristics and design of

ICTs and the extent to which digital technologies are indispensable in mobility, also heavily influence digital exclusion from transport services, and therefore digital inequality. Yet as the reviewed papers reveals, people are increasingly expected to rely on ICTs to access and navigate public transport services. This can be concerning for a public service. Additionally, shared mobility modes often rely on ICTs as a sole mode of access. If these modes are to be further scaled up and promoted with the objective to encourage more multimodality and more environmentally sustainable travel patterns, the question of exclusion becomes more pressing.

There is evidence that digital inequality in transport services is patterned along the lines of socio-economic status. Older adults, women, people with lower education levels, with lower income levels, from minorities and from rural areas are seen as more likely to be vulnerable to digitalisation in transport services. Health and literacy also play a role in vulnerability to digitalisation in transport services. In general, literature acknowledges that digital inequality in transport services is likely to follow and possibly reinforce patterns of social inequality. As such, digital technologies are one piece in a complex socio-technical system that poses challenges for meeting the needs of vulnerable populations in general.

Chapter 4: ‘Who can I ask for help?’: Mechanisms behind digital inequality in public transport

Chapter 3 showed that multiple – and sometimes overlapping – groups are more likely to be impacted by digital inequality in transport services. These include older adults, people with a migration background, people with a lower education level, and people with learning and communication issues. This chapter uncovers mechanisms behind digital inequality in public transport through 39 interviews with individuals belonging to these at-risk groups.

This chapter starts with an introduction (section 4.1), followed by a section where our method is described in details (4.2). Then, we share results (section 4.3): benefits of digitalisation, difficulties associated with digitalisation in public transport and coping strategies. In the discussion section (4.4), we provide insights on patterns across participants, general observations and propose a model that fits together our findings. We finish with a conclusion and a few research avenues (section 4.5).

This chapter is based on the following article:

Durand, A., Zijlstra, T., Hamersma, M., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2023). “Who can I ask for help?”: Mechanisms behind digital inequality in public transport. *Cities*, *137*, 104335. DOI: 10.1016/j.cities.2023.104335

The data that support the findings of this study contain information that could compromise the privacy of research participants and are therefore confidential. The guide that was used to conduct the semi-structured interviews is available in the 4TU repository, at https://data.4tu.nl/datasets/b37db263-f050-4e08-abf5-b8a8ee465a11

4.1 Introduction

While public transport (PT) operators have been historically slow to embrace technological innovations (Nelson & Mulley, 2013; TRCP, 1999), they are catching up. Contactless payment, trip planning apps and online ticketing are nowadays considered basic PT customer services (Palacin, 2021; UITP, 2017). Mobility services running though apps increasingly shape people's choices and preferences, particularly in urban areas (Vecchio & Tricarico, 2018).

The development of digital technologies in public transport services has been accompanied by much enthusiasm that digitalisation will unfold social inclusivity effects. Nevertheless, scholars question this assumption (Banister, 2019; Pangbourne et al., 2020) and have raised concerns around a growing digital divide (Vecchio & Tricarico, 2018; Zhang et al., 2020). Digital inequality in transport services refers to the unequal access to transport services – from buses to shared bikes and on-demand services – due to digitalisation (Durand et al., 2022) (Chapter 3 of this dissertation). Durand et al. (2022) (Chapter 3 of this dissertation) show that multiple – sometimes overlapping – groups are more likely to be impacted by digital inequality in transport services. These are older adults, people with a lower education level, people with a lower income, people with a migration background, people living in rural settings, women (especially in countries where women are less emancipated) and people with learning and communication issues. There are multiple reasons why these groups are more likely to be negatively impacted by digitalisation. These reasons range from a distrust in technology to the costs of smartphones and a poor design of digital services (Durand et al., 2022).

Previous research on digital inequality in transport services has frequently focused on one particular group of individuals. Older adults are relatively frequently investigated (Bertolaccini & Hickman, 2019; Butler et al., 2021; Carney & Kandt, 2022; Gould, 2020; Harvey et al., 2019; Kos-Łabędowicz, 2020). A few other studies focus on people with a cognitive impairment in particular (Bigby et al., 2019; Van Holstein et al., 2021). These studies offer relevant insights, yet they do not allow for conclusions to be drawn across multiple groups of individuals. In parallel, a few studies have investigated digital inequalities in transport services in the general population through quantitative and offline surveys (Bosch et al., 2021; Goodman-Deane et al., 2021; Groth, 2019; Zhang et al., 2020). Yet because questionnaires need to be concise, these studies provide a somewhat bounded understanding of the mechanisms of digital inequality in transport services.

To study these mechanisms, we decided to focus on one type of transport service (public transport) in a (mainly urban) region. This particular focus answers the call of Lam and Ma (2019), who recommended to investigate the digital divide by focusing on a specific context. Besides, we decided to shed light on coping strategies. 'Coping' is a term from psychology that refers to the way people deal with problems or stressful situations (Lazarus & Folkman, 1984). The term 'strategy' refers to the relatively systematic nature of the coping. Analysing coping strategies allows to gain a better understanding of how people deal with a situation in which they are a priori disadvantaged. In light of the above-mentioned gaps and our scope, we formulate our research question as such: *how do groups who are more at risk of digital*

inequality experience digital transformations in public transport, and what are the coping strategies they might have developed in response to it?

We conduct this study in the Netherlands, where the public transport sector is leveraging on the opportunities offered by digitalisation (Council for the Environment and Infrastructure, 2021; Government of the Netherlands, 2021). A smart card has been available nation-wide since 2012 (Van Oort et al., 2015), buses have been cashless since 2018 (OVPro.nl, 2018), online trip planning is widespread and the amount of ticket offices in stations will be halved in 2022 (SpoorPro.nl, 2022). Yet while the Netherlands is the front runner in Europe in terms of (mobile) internet coverage and basic digital skills (Statistics Netherlands, 2018, 2020), there are important differences in the population. 19% of the population aged 12 and older has no or low digital skills, but this statistic rises to 21% for people with a non-western[12] migration background, 36% for people with a lower education level and 43% for people over 65 (Statistics Netherlands, 2019a). We focus on these particular groups in this study.

Although this study is based in the Netherlands, it offers relevant insights for international researchers, policymakers and practitioners for two main reasons. First, digital inequality in transport services goes beyond the Netherlands (Durand et al., 2022; Goodman-Deane et al., 2021; Kedmi-Shahar et al., 2020). Second, although mechanisms at play behind digital inequality are likely somewhat context-dependent, we argue that the mechanisms as studied in the Netherlands are interesting to an international audience. This is particularly the case for those interested in transport-related social exclusion, where digital inequality is one of the (underresearched) dimensions (Luz & Portugal, 2021; Lucas, 2019). Besides, the leading position of the Netherlands in terms of digitalisation in general makes it an interesting case. Indeed, such a position offers the opportunity to investigate what happens for certain population groups when digitalisation becomes so embedded in society.

4.2 Method

4.2.1 Global setup and theoretical lens

We interviewed 39 participants and conducted a rigorous qualitative data analysis, as detailed below. We conducted one-on-one interviews as they allow for personal matters to be discussed by removing normative pressures (Clifton & Handy, 2003).

In this research, we adhere to a critical realist position. It assumes the existence of an independent reality but also accepts that there may be varied interpretations of reality due to a difference in context (Saxena, 2021). Indeed, what we – as highly digitally skilled people and mostly experienced PT users – would define as a *difficulty* with digitalisation in public transport may well be perceived as a normal process for some participants. For critical realists, the way facts are perceived, 'particularly in the social realm, depends partly upon our beliefs and

[12] Note that the use of the term 'non-western' is no longer recommended by Statistics Netherlands as of 2022; this development happened after this paper was written and submitted.

expectations' (Bunge, 1993, p. 231). Critical realism-based research seeks to identify mechanisms underpinning events; in this case, the mechanisms at play behind digital inequality in transport services. This lens had consequences both on the fieldwork and on the analysis of transcripts, as explained in the rest of this section.

4.2.2 Sampling

We used a mix of two purposive sampling techniques to recruit participants. First, we used *maximum variation sampling*. It consists of deliberately including variation in our sample (Patton, 2014), which we did on two dimensions:

- **Access to digital technologies**. To recruit people with various degrees of access to technology, we relied on three main factors: material access to digital technology (specifically, access to a smartphone, a tablet or a computer), digital skills and diversity in use of digital technologies. This is a simplification of the concept of *access to technology* as inspired by research on digital inequality (Van Dijk, 2005) and presented in Durand et al. (2022). The reason for this simplification is that these three aspects were the easiest to ask during the recruitment and to control during the interviews. The three levels of this dimension are shown in Table 4.1.
- **Use of public transport**. We recruited people with three levels of experience with public transport, as shown in Table 1. The use of public transport is based on estimates of participants before the COVID-19 pandemic. Most public transport users were recruited early enough in the pandemic (second half of 2020) to remember what their public transport use was like before March 2020. The cut-off for 'Frequent PT usage' needed to be simple. We chose *once a month or more* as frequent public transport use. Around 37% of the Dutch population used public transport at least once a month in 2019 (Statistics Netherlands, 2019b).

Since we were mostly interested in people with lower digital access, we purposefully sampled more of them (Table 4.1). This is called *intensity sampling*. It consists of focusing on information-rich cases that manifest more the phenomenon of interest (Patton, 2014) – here, people who are less comfortable with digital technologies.

In addition to these sampling techniques, we added two criteria. First, we only recruited people who are able to live and to travel independently. Second, in order to be able to focus on digitalisation, we excluded variations in public transport supply by recruiting exclusively people living close to PT, e.g. at most 300 metres away from a train station or a bus stop with at least 4 buses per hour. As such, urban and peri-urban areas were a main point of focus.

Participants were recruited through multiple organisations throughout the Netherlands. These organisations are welfare and care institutions, a nation-wide organisation for people with low literacy levels, workplaces for people with impairments, community centres as well as advocacy groups for people with a mild cognitive impairment or for older adults. A dozen organisations were contacted. Key contact persons in such organisations assisted in recruiting participants by spreading flyers (both digitally and offline) within their network. They also helped pre-

screening participants based on the aforementioned criteria. A second screening took place once the team assisting the interviewer had a first phone contact with participants.

As previously mentioned, we focused on people with a non-western migration background, older adults and people with lower education level. For the latter, we chose to focus mainly on two sub-groups for which we deemed digital inequalities to be most relevant, namely people with a mild cognitive impairment and people with lower literacy skills. As low literacy concerns one in six Dutch person aged 16 and older (Netherlands Court of Audit, 2016), this is considered an important social issue.

4.2.3 Data collection

We chose to conduct semi-structured interviews tackling multiple aspects. Semi-structured interviews entail a set of clear instructions in a topic list to be followed by the interviewer, yet with enough freedom to follow leads from the interviewee (Russell Bernard, 2011, pp. 157-158). We used many open-ended questions, as recommended by Saxena (2021) for critical realism-based research. The main topics addressed in the interview were:

- Activities, social participation and travel behaviour.
- *If use of PT*: Current practices related to planning, paying for a trip, looking for information during the trip, responding to disruptions. Role of digital technologies in each of these actions.
- *If no use of PT*: Hypothetical trip with PT and use of digital technologies.
- Use of and attitudes towards digital technologies in general.

All of the interviews were conducted by the same interviewer from an agency experienced with both reaching and interviewing hard-to-reach groups. The interviewer was fluent in Dutch, had broad experience with interviewing the target groups of this study and was trained on the topic through meetings and a pilot interview in the presence of the first author. The study protocol was approved by Delft University of Technology in September 2020. Interviews ranged from 30 to 90 minutes and were recorded with participants' permission. The interviews were conducted during the COVID-19 pandemic (September 2020 – April 2021). For this reason, not all interviews could be done face-to-face. Participants were left the choice of how they wanted the interview to be conducted. Nineteen took place face-to-face, at a location chosen by the respondent, while twenty were done by phone. An interpreter was available in a few cases. We stopped at 39 interviews as few new insights were being discovered in the last few interviews. Furthermore, Deterding and Waters (2018) deem 30 interviews or more a relatively large number for studies with a semi-structured protocol. The composition of the final sample is shown in Tables 4.1 and 4.2. In the Results section, respondents will be referred to after quotes with the letter R, followed by a number, their gender, age, and the typology shown in Table 4.1. Additional details about our sample are given in Appendix C.

We were mostly interested in the pre-pandemic behaviour of participants. Nevertheless, because we expected that participants would want to talk about their situation during the pandemic, we

reserved around five to ten minutes at the beginning of each interview to talk about their experience of travelling during the pandemic. After this, respondents were invited to answer questions with the pre-pandemic situation in mind. The interviewer would regularly remind them if needed.

Table 4.1: Composition of the final sample in terms of our two main sampling dimensions

Public transport use **Digital access**	**Frequent PT use** **Using PT more than once a month**	**Infrequent PT use** **Using PT at least once a year, at most once a month**	**No PT use** **Using PT less than once a year**	**Total**
High digital access: more digitally self-reliant Material: smartphone and computer Skills: positive self-assessment, rarely/never needs help Usage: high diversity	4	1	0	5
Medium digital access Material: smartphone and computer / smartphone only / computer only Skills: positive or negative self-assessment, but needs help sometimes Usage: high or low diversity	7	5	1	13
Low digital access: less digitally self-reliant Material: smartphone and computer / smartphone only / computer only / none Skills: positive or negative self-assessment, but often needs help Usage: low diversity (usually mainly leisure/social)	5	10	6	21
Total	16	16	7	39

Table 4.2 Composition of the final sample (some participants belong to more than one group)

Name of the group	**Description of the group**	**Number**
Young older adults	Adults aged 65 to 74 included	17
Old older adults	Adults aged 75 and older	10
People with a lower education level	Adults with a lower education level following the classification from Statistics Netherlands, with a focus on people with low literacy skills and people with a mild intellectual impairment	23
People with a migration background	Adults with a non-western migration background following the classification from Statistics Netherlands (people from Turkey, Africa, Latin America and Asia excluding Indonesia and Japan)	10

4.2.4 Data analysis

All of the interviews were transcribed verbatim. Afterwards, they were uploaded in a qualitative data analysis software (ATLAS.ti 9). The first author was the main analyst and conducted a large part of the analysis in ATLAS.ti. The first author shared and discussed findings with co-authors at least every other week during the analysis period. This was done to ensure confirmability of the results, i.e. the extent to which the study's findings are supported by the data (Shenton, 2004). Besides, two co-authors had access to the transcripts and the first author was directly in contact with the interviewer to discuss findings. The 'we' in the following paragraph therefore refers to the first author in close cooperation with a team.

We followed a flexible coding approach (Deterding & Waters, 2018), working in three steps:

- First, we read each transcript and indexed them based on the topic list. Parts of the interviews that were about participants' situation during the pandemic were delineated at this stage. In this step, we already started writing memos to be reflexive of our interpretations, to develop case summaries and cross-case analyses, as recommended in qualitative research (Kuckartz, 2014).
- Second, we applied analytic codes. The coding scheme was structured along the two main axes of our objective: experiences with digital transformations in public transport and coping strategies. A combination of inductive and deductive approaches was used:
    - For experiences with digital transformations, we mostly used a deductive approach. For this, we relied on the digital inequality framework introduced in Durand et al. (2022) and shown at the beginning of the Results section.
    - For coping strategies, we started with an inductive approach and later introduced literature on coping strategies (Asmar et al., 2020b; Lazarus & Folkman, 1984).

      We coded both at a semantic level and at a latent level. Coding at the semantic level means focusing on the explicit and obvious content of the data. Latent codes identify meanings beneath the semantic surface. The latter are especially important for the identification of coping strategies, which are seldom directly verbalised by participants. Since the main analyst was not present for most interviews, she listened to the tapes in order to detect these more hidden meanings.

      The authors assessed whether certain experiences of participants would constitute a potential difficulty with digitalisation, and subsequently result in a coping strategy. At the same time, we made room in our coding scheme for the participants' perception. For each item coded as a potential difficulty, we coded the extent to which participants experienced this as a difficulty too or not. This distinction proved fruitful to propose our model in the Discussion section.
- Third, we explored how deeply our results are grounded in the data. The main analyst and the interviewer had regular contact to brainstorm these results. Furthermore, we relied on the querying possibilities in ATLAS.ti, investigating whether participants had been misclassified along codes and whether diverging patterns had not been too overly stressed.

4.3 Results

In this section, we first focus on how participants experience digitalisation in public transport: the benefits (section 4.3.1) and the difficulties (section 4.3.2) they experience. Figure 4.1 shows the coding categories we used, organised according to the conceptual framework to investigate digital inequality introduced in Durand et al. (2022). Durand et al. (2022) argue that this framework, adapted from Van Dijk (2005), is a useful departure point to understand digital inequality in transport services. In short, the model of Van Dijk (2005) posits that inequalities in terms of personal position and background result in inequalities of access to digital technologies, which in turn translate into disparities in terms of participation outcomes. On this latter point, we chose to make a distinction between benefits and disadvantages in the analysis, as shown in Figure 4.1. We did not apply a deductive coding strategy for disadvantages because they cannot be discussed separately from coping strategies. This is why we will turn to these disadvantages in the Discussion section. Second, we present the results of how people cope with digitalisation in public transport (section 4.3.3). We shed light on various types of coping strategies via our inductive approach.

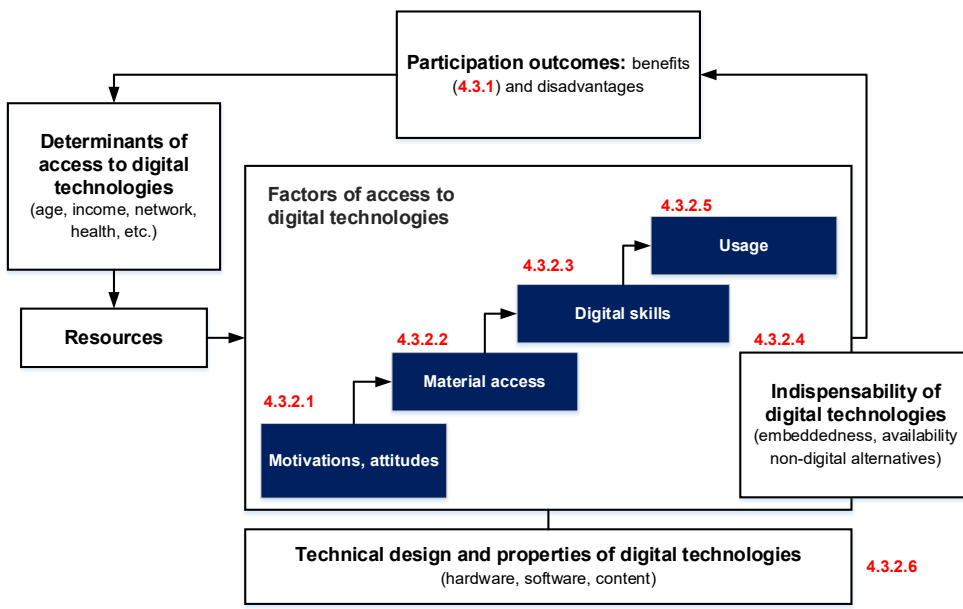

Figure 4.1: Organisation of the results pertaining to experiences with digitalisation, as part of the conceptual framework to investigate digital inequality (see Durand et al. (2022), based on Van Dijk (2005)).

4.3.1 Benefits of digitalisation

Public transport users recognise the benefits of digitalisation. Half of the participants indicate that they experience benefits with respect to paying and planning. Several participants consider that being able to prepare their trip from home using a tablet or a computer is a nice possibility. Thanks to multimodal planners, people get an idea of the door-to-door journey. Furthermore, the availability of real-time travel information on the smartphone gives people the opportunity to adjust their plans just before departing or during the journey. This provides a sense of control:

> '*I get comfort out of it [travel app] [...] for a train that goes once every half hour, I like it. And that gives me a good feeling indeed. And you can indeed see whether there are any disruptions. [...] It gives me a good feeling.*'
>
> R4, woman, 66, medium digital access, frequent PT.

Half of the participants mention benefits of digitalisation in relation to travel payments. They almost always refer to the advantages of the ov-chipcard, the Dutch smartcard that can be used to access all PT modes in the Netherlands. The smartcard saves them time and energy, as it can be quickly topped up from machines or online. The possibility to let the smartcard automatically recharge leads to a lot of satisfaction, when this functionality is activated. It also offers a way out for those who feel uncomfortable with ticket vending machines. A few respondents even stated that they were travelling more, thanks to the convenience of the ov-chipcard:

> '*The nicest thing about public transport, is when that ov-chipcard came out. […] I started travelling a lot more. You didn't have to buy a ticket, you didn't have to go to the ticket office, the money would be taken out of your account automatically, I didn't have to worry about that.*'
>
> R15, woman, 75, low digital access, frequent PT.

4.3.2 Difficulties associated with digitalisation

4.3.2.1 Lack of motivation and fear

Despite the above-mentioned advantages, potential and actual public transport users also experience various difficulties linked with digitalisation. One of them is that people can feel discouraged from using digital services for various reasons:

- Some can find online travel information, but not the piece of the information they are looking for, such as the presence of toilets in public transport or the accessibility of stations and stops. There is a mismatch between the available information and people's own information needs (Pangbourne et al., 2010).
- Infrequent and non-PT users who are less digitally self-reliant explain that the time and energy investment required to understand digital technologies is often not worth it. As such, they get discouraged from learning about smartcards and online travel information systems.

- In addition, the fear of cybercrime hinders certain online activities, such as buying e-tickets. This finding is in line with previous literature (Harvey et al., 2019; Musselwhite, 2019).

> '*No, no, no! I don't transfer money via the internet. No, because you are always warned. There are far too many criminals on the internet. I don't want to be trapped by them.*'
>
> R6, woman, 83, medium digital access, infrequent PT.

4.3.2.2 Lack of or inadequate devices

The lack of ownership of the right devices, such as a computer or a smartphone, is an obvious obstacle to reaping benefits of digitalisation. Malfunctioning software, old devices, unstable operating systems, dead batteries, a limited data bundle, no wired internet and high costs can also be barriers, as already described in literature (Golub et al., 2019; Groth, 2019). Furthermore, having only a smartphone is not sufficient. Comparing prices and managing files, for example when filing a complaint, is harder on a mobile device. In general, we found confirmation that the ownership of a device is a poor indicator of the extent to which people reap benefits or are guarded against difficulties of digitalisation in public transport. This is in line with digital inequality research (Van Dijk, 2005).

4.3.2.3 Low digital skills

Some people lack the necessary digital skills to use online travel information or obtain a ticket. It may concern basic digital skills, such as installing apps or activating mobile data. Yet these skills form the precondition for more advanced skills. Information and strategic skills are particularly relevant (Vecchio & Tricarico, 2018). Yet half of our participants showed low levels of such skills. They cannot request an ov-chipcard, buy a ticket for an international bus service or manage subscriptions (that require creating an online account). Additionally, some people know how to find one piece of information (e.g. bus line number), but not all the information they need (e.g. departure time of next bus).

Digital skills also play a role in operating ticket vending machines. Challenges lie in the use of the touch screen, fear of making the wrong choices and being unable to make corrections, understanding the displayed information and, ultimately, making choices. When added up, these challenges can lead to stressful situations:

> '*At the moment I wouldn't dare [using a ticket machine]. I think if I had to go and buy a ticket now, I'd get really high blood pressure and my heart rate would go right up. I know that for sure. I would also be afraid of losing my bank card.*'
>
> R10, man, 61, low digital access, frequent PT.

4.3.2.4 Low digital flexibility

Dealing with the new, more or less formal rules that digitalisation brings along can be a challenge for some people. This requires a meta-skill called digital flexibility. It is about the ability to move easily between platforms and services (Asmar et al., 2020a). We identified low

digital flexibility on multiple levels. To begin with, some may have difficulties dealing with the fast pace of digital transformations, such as changes in the ticketing system and updates that modify apps overnight. Others report that cash-free payments (bank cards or smartcards) make transactions harder to follow. They are deemed too abstract and not tangible enough, sometimes leaving the perception that prices have dramatically increased. Next, the decrease in availability of public transport staff at stations raises concerns, as do the increasing expectation that people have access to real-time travel information. Such expectations can manifest implicitly, for instance when people have the feeling that they need a smartphone to travel. They can also manifest explicitly:

> '*Someone from [PT operator], yes. He took out his mobile phone, he looked on the internet and he said: "Yes, here it is, you should have had a look." I said: "Yes, it's only just now, because I have another train here." "Yes, but it's not running, it's cancelled. You'll have to look on the internet, then you'll know what's running." And then he was gone.*'
>
> R8, woman, 68, medium digital access, infrequent PT.

Finally, the fast uptake of digital technologies in public transport has led some participants to mistakenly believe that some analogue options have completely disappeared. For instance, they believed that the possibility to request money back after a disruption via a service desk was gone. This likely reinforces the operator's conviction that analogue channels are becoming superfluous.

4.3.2.5 Not using digital technologies on-the-go

The trend towards an increasingly mobile use of digital technologies fits well with the act of travelling: people can access the internet on-the-go. However, the mobile use of technologies is not evident for everyone. Some participants exclusively use their smartphone at home. Reasons not to use it on-the-go include low skills, stress, a lack of access to wi-fi, no or not enough data, ergonomic difficulties and an outdated phone. Not using digital technologies on-the-go particularly creates difficulties when disruptions occur. As highlighted by Bertolaccini and Hickman (2019), it shouldn't be expected that everyone can access information on-the-go.

4.3.2.6 Problems with the design of systems in public transport

The interviews highlight the importance of an inclusive design, from websites to ticketing systems. For instance, tiny letters can create an additional barrier in the search for travel information. New apps or updates of previous apps are not always compatible with assistive technologies, such as screen readers. The ticketing system in general can also create challenges for some people. The combination of paying for the ov-chipcard, paying for a subscription and paying for a journey appears sometimes difficult to understand. Rules are not always clear, highlighting the importance of clear communication. For instance, some participants do not know whether they can get the off-peak discount if a part of their trip was done in the peak hour. They also do not know where to find that piece of information. As already highlighted in

literature, we find confirmation that both hardware and software can create barriers (Durand et al., 2022).

4.3.3 Coping strategies

4.3.3.1 Support

A main way to cope with digitalisation in public transport is to rely on **support from their social network**: a partner, children, grandchildren, parents, friends, neighbours, fellow volunteers or colleagues. Around half of the participants used this coping strategy. This finding is supported by literature, both in transport (Kos-Łabędowicz, 2020; Misra et al., 2022) and in general (Dedding & Goedhart, 2021). We found three types of social support, aligned with digital inequality research (Asmar et al., 2020b):

- Support though guidance. It consists of explanations, advice and feedback on how to use certain digital services like public transport operators' websites. Whether the help is spontaneously offered depends on the level of intimacy with the one helping. Digital inequality research confirms the importance of intimacy in predicting the possibility to find support in one's network (Asmar et al., 2020b).
- Support through substitution. It consists of people performing tasks for others without any specific goal to teach the supported person. They act as proxy users. People facing difficulties with digitalisation can make use of this type of support for a one-time action, like installing an app, creating an account or printing an e-ticket.
- Emotional support. The social network can play the role of motivator or safety net. Knowing that they have access to a close source of support can give people the confidence and the motivation to at least experiment with digital tools. Some participants explain that they only undertake certain actions, such as looking for travel information, because they know they can fall back on someone if needed:

  '*Well, two days in advance I am already working on preparing my trip [...]. How should I do that? How am I going to do that? Who can I ask for help? That's where it starts.*'

  R10, man, 61, low digital access, infrequent PT.

Relying on one's social network comes with advantages: assistance is close and familiar and there is a good understanding of each other's needs (Van Dijk & Van Deursen, 2014). Yet it comes with pitfalls. We identified three of them:

- The social network is not necessarily a sustainable form of assistance. This is particularly the case when people rely on a few people and when they are mostly supported by proxy users. Indeed, this does not foster learning. Older adults who systematically rely on their partner are particularly vulnerable, as summarised by a participant:

> '*I'm still used to having my husband, but it would be different if he were to pass away, and then I would be in a difficult situation.*'
>
> R15, woman, 75, low digital access, frequent PT.

- Family and friends are not always available, either because they live too far or because they do not have enough time to help. Participants also expressed a reluctance to burden their network, resulting in asking help on one aspect but not on another, or postponing a trip.
- People may have no one to turn to in their close network. Their family and friends may even be discouraging them from learning digital skills or getting a computer. Furthermore, it is not always easy to find someone who both knows how public transport works and who is comfortable with digital tools. This may lead to a form of resignation:

> Interviewer: '*And are there things you would still like to learn to do by yourself on your phone?*'
>
> Participant (via interpreter): '*I think this is enough already*.'
>
> Interviewer: '*Oh, you are satisfied. Yes, okay. And for example, if I say that travel information can also be found via the phone, would you be interested in that? Travel information for public transport.*'
>
> Participant (via interpreter): '*Yes, but who is going to teach me? [...] I don't know.*'
>
> R37, man, 71, low digital access, frequent PT.

Some of the respondents cope with digitalisation in general by relying on **formal sources of support** like volunteers and computer courses. In a few cases, this proved useful to cope with digitalisation in public transport too. Computer courses can give people the confidence to try using digital technologies. Yet they do not always guarantee that people will be able to translate these skills in public transport. In general, respondents who followed a course explained that their social network was important to help them practising and to teach them additional skills, such as how to use a travel planner. Other than courses, respondents mention that volunteers, social workers and care coordinators can provide them with punctual help, like to buy an e-ticket. The role of care coordinators in such tasks has been extensively documented in Oluyede et al. (2022).

Another way to cope with digitalisation in public transport consists of finding **support in the transport system itself**. Interviewees indicate that favourable responses by fellow travellers can be very helpful. They can help for quick actions. For instance, a few participants explained that they would look for people with a smartphone to ask them information when feeling uncertain about their trip. Others explained that they rely on the help of fellow travellers acting as proxy users to buy a ticket. Relying on other travellers can also give people the opportunity to successfully learn on-the-job.

Public transport staff can also offer assistance. A majority of the interviewed public transport users regularly rely on such support. It can be about asking for reassurance, getting travel

information or getting a ticket. Service desks can also be used for punctual and seemingly small actions, but with large impacts. One of such examples is help activating an option on the smartcard or requesting a smartcard: these are done once and do not need to be repeated. Most interviewed non-PT users cannot imagine starting using public transport without being able to directly talk to a member of staff. A few participants explained that they would go to great lengths to find a station with a service desk. For example, they would bike one hour (one way), make special detours or go by car:

> Participant: '*Then I went all the way to [place] with my car to buy a ticket, to have that for my trip. Then I could go straight on, because I already had that ticket.*'
>
> Interviewer: '*Yes, you bought it on another day.*'
>
> Participant: '*Yes. Another day and at another station with a ticket office, yes.*'
>
> R19, woman, 79, medium digital access, infrequent PT.

As such, this strategy can involve a form of hidden work. Extra costs are not uncommon. Participants highlighted that discounted tickets are not available at service desks, and topping up smartcards or getting a ticket there comes with a small extra fee (except for people aged 75 and older and people with impairments).

4.3.3.2 Other coping strategies

People who cannot or won't access support, whether it be punctually or structurally, develop other coping strategies. One of them is **fare evading**. It means not paying for a ticket or not buying the right ticket. A few participants mention this. It can be intentional or unintentional, as Delbosc and Currie (2019) explain. The main reasons for fare evading indicated by participants are difficulties using ticket vending machines, confusion about the ticketing system or the impossibility to locate a vending machine when needed. Sometimes, the interviews also revealed financial issues, which could play a role in deciding not to pay.

For people who do not have access to travel information on-the-go specifically, a common way to cope is to **write down all the travel information** they need on a piece of paper or print a travel advice. Even some participants who can access their smartphone on-the-go use this strategy. Some people reported writing information for alternative journeys, in case something might go wrong. When the trip does not go as planned, a few participants explained that they would rely on support from staff or fellow travellers. When this was not available or helpful, they would **go back home**. This is even the case for those who have a smartphone and cannot or do not want to use it on-the-go.

At the other extreme, some participants with a low digital access explain that they mostly take trips **without consulting any prior travel information**. They do not remember schedules and are neither willing nor able to look for travel information online. This may lead to long waiting times, particularly in the case of low frequencies:

> '*We check when the bus comes once we are at the station [...] They often come every half hour or so. So then if it has just left, then you're out of luck, you have to wait half an hour.*'
>
> R9, woman, 74, low digital access, frequent PT.

A few participants mention that they **avoid using public transport for unknown destinations**, even when public transport would be a suitable option. Those with access to a car argue that it is more convenient. Digitalisation may well have nothing to do with such a choice. Yet a few of these participants mention bad experiences when searching for public transport travel information. They could not find the information they needed or used wrong information and got lost. In their interviews among older adults in Sweden, Olausson and Kamel (2020) also noted that some participants would be relying more on their car and using less public transport because of digitalisation.

Some public transport users do not seem to know how to look for online travel information and are simply used to travelling by public transport along the same routes. A few expressed the wish to explore places beyond the well-trodden paths, but encountered too many difficulties along the way and could not find adequate support. Non-PT users who are less digitally self-reliant and have no car access did not explore much beyond their neighbourhood. Other factors (poverty, loneliness, etc.) might play a role and people may have adjusted their preferences. Yet a few explained that having more digital skills would make it easier to start using PT, like the following participant:

> '*That would make it easier to travel by public transport, if I were more digitally literate. I would like to participate more in society. Especially the family, acquaintances and friends who live further away. […] I would be able to do much more if I could travel more.*'
>
> R38, woman, 68, low digital access, no PT.

4.4 Discussion

4.4.1 Patterns across participants

We uncovered some patterns in terms of who experiences difficulties. Note that these patterns are meant to have a theoretical generalisability, and not a generalisability to the wider population. Firstly, those who name benefits are often more digitally self-reliant and use public transport frequently. Secondly, older adults aged 65 to 74 with a medium to higher education level and without a migration background encounter fewer to no difficulties. This highlights the need for researchers to look beyond this relatively easy-to-reach group when investigating the impacts of digitalisation in transport services. Thirdly, participants experiencing difficulties are usually less digitally self-reliant. This can make access to public transport particularly complex for non-PT users who are less digitally self-reliant.

In line with digital inequality research (Helsper & Van Deursen, 2017), we find that people who experience the most problems with digital technologies may be the ones with fewer opportunities to receive high-quality support. A majority of the respondents relying on their social network to cope with digitalisation in public transport have a medium digital access. People reporting being unable to rely on their social network are usually less digitally self-reliant, have more frequently a migration background and mentioned money concerns at some point in the interview.

A majority of the participants experience at least one difficulty linked with digitalisation in public transport. Importantly, we note that people can reap benefits on one aspect and experience difficulties on another. For instance, one may enjoy the benefits of real-time travel information but be uncomfortable with a smartcard.

4.4.2 The self-reliance paradox

Our study confirms that digital technologies can promote self-reliance among travellers. However, this is not the case for everyone. Digital technologies facilitate a self-service approach that puts marginalised users at risk, as both Van Holstein et al. (2021) and Oluyede et al. (2022) already noted in the context of urban transportation. Digital technologies actually makes people who are less at ease with digital technologies more dependent on others. As a participant puts it when explaining her difficulties with ticket vending machines:

> '*Then you are again dependent on someone else to support you and help you with that. Yeah that can be very difficult. And again, you have to dare to ask.*'
>
> R12, woman, 41, medium digital access, frequent PT.

In other words, the great emphasis on personal responsibility through digitalisation actually reduces the self-reliance of some citizens. This is called the self-reliance paradox (Keizer et al., 2019).

4.4.3 Visualising mechanisms behind digital inequality in public transport

Digital inequality in transport services is the result of a combination of a lower access to digital technologies and the use of certain coping strategies. Our analysis allowed us to make links between potential difficulties experienced by participants and coping strategies. Participants' perceptions play a key role here. In instances when participants acknowledged that they face a difficulty related to digitalisation in public transport, we see that they would try to seek support. In instances when they are satisfied about their situation – while we assess that they might be facing a difficulty – we see other types of coping. We give here an example of such a situation. A participant repeated twice that she is perfectly happy with the travel information she can find online. Yet whenever something unexpected would occur (her usual travel information website is temporarily down, or she needs to look for a different piece of information), she would find herself stuck. She is unable to navigate other popular travel information websites. We coded

this as a potential difficulty in terms of digital skills, even though she does not explicitly acknowledge it as such.

We deemed the link between coping strategies and participants' perceptions important to explain mechanisms of digital inequality. In fact, coping strategies are responses to how stressful events, or difficulties, are perceived. We therefore propose a model that fits together our findings, based on the transactional stress model developed by Lazarus and Folkman (1984). This model has been applied in other fields too, like cyberbullying (Parris et al., 2012), social media use (Wolfers & Schneider, 2021) and students' well-being (Dvořáková et al., 2019). In their model, Lazarus and Folkman (1984) described *coping* as a process resulting from the relationship between the stressor and available resources. They argued that when facing a potential stressor, one conducts a primary and secondary appraisal. The primary appraisal stage requires assessing the situation to determine the extent to which there is a difficulty or threat. The secondary appraisal stage involves the person evaluating their resources and taking action accordingly. Decisions made during each stage will elicit certain coping strategies.

We propose that when facing a potential difficulty pertaining to digitalisation in public transport, people also conduct two – conscious or unconscious – appraisals. To begin with, they assess whether they are facing a difficulty. For instance, *is not managing to get this piece of travel information a difficulty for me at the moment?* Or: *can I manage with the ticket vending machine on my own?* When people do perceive a difficulty, they assess whether they have the resources to do something about it. They may ask friends, family, neighbours, colleagues, summon the courage to ask questions to strangers at the station, put in the money to call a helpline for assistance, etc. In circumstances when such resources are available, people are able to get support. In other circumstances, we see different strategies such as fare evading, postponing the trip, accepting potentially longer journeys, travelling less with public transport or going back home. These last few coping strategies are also used by those who do not seem to perceive a difficulty about the situation they are facing. This proposed model is shown in Figure 4.2. The three boxes on the right side serve as labels to the different parts of the model.

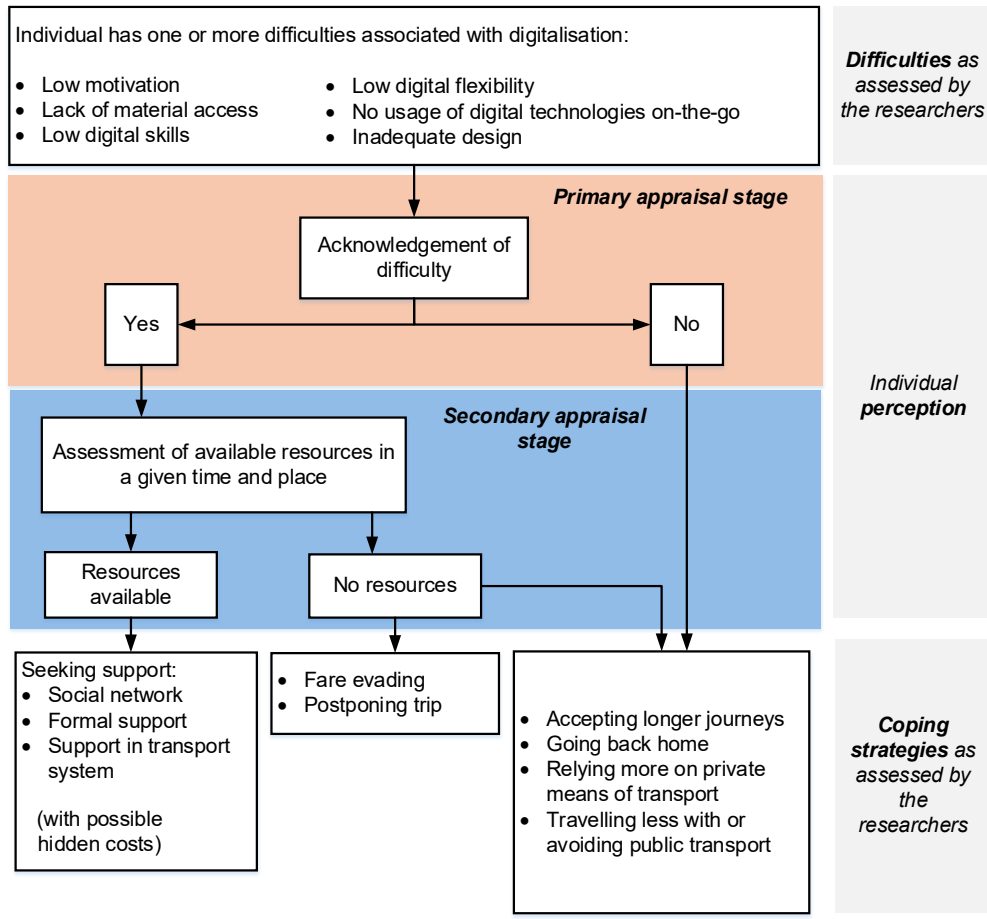

Figure 4.2: Proposed process model of coping with digitalisation in public transport, inspired by Lazarus and Folkman (1984).

Our proposed model depicts several mechanisms at play behind digital inequality in public transport. Getting support seems like the best course of action. Yet it sometimes comes with pitfalls, as explained in section 4.3.3.1: family and friends are not always available or helpful, getting a ticket from a ticket office desk may require a long detour and extra money, etc. The other coping strategies reveal more visibly mechanisms of digital inequality in public transport, ranging from postponing a trip and fare evading to avoiding public transport altogether. We note that a particular person is not necessarily bound to a single path: one may manage to get help once, and decide to postpone a trip the following time. Additionally, this model does not encompass the spontaneous or preventive support one may receive (mostly from their close social network). The paths in this model are based on our empirical material. We do not exclude that further research on this topic finds slightly different paths, for instance between not acknowledging a difficulty and fare evading.

This model adds value to the conceptual framework presented in Figure 4.1 because it allows for a person-centred understanding of the mechanisms behind digital inequality. Specifically, this model shows how a lower access to digital technologies coupled with a limited access to resources can put people at a disadvantage when dealing with digitalisation in transport. Nevertheless, experiencing difficulties with digitalisation in public transport does not systematically translate into exclusion from public transport. This is even the case for people with a lower digital access. Instead, there are different layers of disadvantage. In line with digital inequality research (Asmar et al., 2020b), we find that social resources can be translated into digital resources among those willing to learn and receiving support through guidance. Half of the less digitally self-reliant participants were able to find some support in their social network.

4.4.4 Limitations

Our research has a number of limitations. The first lies in the recruitment of respondents. Although we succeeded in speaking to a diverse group of respondents, our group is likely to contain more people who are proactive in learning digital skills, and relatively fewer who are truly excluded. Someone who is proactive in learning digital skills is also easier to recruit because they will be in touch with an organisation that offers courses or support to this person. Still, there were also many participants who were not in touch with such organisations. We paid a lot of attention to their perspective during the analysis.

The interviews took place just before, during and after the second COVID-19 wave in winter 2020/2021. We aimed to limit the influence of the pandemic on our respondents' interviews, as discussed in the methods. Most respondents were able to talk about the pre-pandemic situation, but a few had more difficulty doing so. The interviewer regularly reminded them that the answers to the questions had to be about the pre-pandemic situation. Where respondents did not comply, we marked the passage in the transcripts. It is therefore possible that we missed a couple of respondents' experiences of digitalisation in public transport because they were worried about the pandemic.

4.5 Conclusions and further research

This study aimed to understand how various groups who are more likely to be impacted by digital inequality experience digital transformations in public transport, and the coping strategies they might have developed in response to it. Our interviews reveal that one can reap benefits of digitalisation and experience difficulties at the same time. Access to travel information and smartcards have brought benefits among many of the participants, especially among frequent public transport users and the more digitally self-reliant ones. Using the framework of digital inequality introduced in Durand et al. (2022) as a guide, we see that low digital skills, not using digital technologies on-the-go, not possessing the right devices and a complex design of technologies can indeed pose difficulties. We also unpacked the concept of ‘adapting to the new rules’ brought about by digitalisation in transport services and hinted at in literature (Van Holstein et al., 2021), coined *digital flexibility*. It refers to the ability to adapt to

the constant changes brought about by digitalisation, such as app updates, cash disappearing or fewer ticket offices.

Nevertheless, experiencing difficulties with digitalisation in public transport does not systematically translate into not using or not daring to use public transport. Coping strategies play a role in this, with support from individuals' social network as a main strategy.

Investigating coping strategies sheds light on the various mechanisms at play behind digital inequality in public transport. Our proposed process model of coping with digitalisation in public transport shows that the extent to which difficulties translate into disadvantages for the access and use of public transport depends on one's perception of the difficulty and on their coping resources. These copings resources depend on a myriad of factors: individuals' broader socio-economic context, their social network, financial resources and other transport options. Coping strategies serve a purpose and may even result in people becoming more digitally self-reliant in PT. However, they may also come with risks and pitfalls, involving hidden work and costs, or preventing people from accessing the best prices. This highlights the insidious nature of some mechanisms of digital inequality in public transport. In the language of transport planners, using these coping strategies would amount to raising generalised costs, where travel costs, travel time and comfort components are impacted. While many people may gain self-reliance through digital technologies, this study highlights clearly the existence a self-reliance paradox. Those who are less comfortable with these digital technologies are likely to become even less self-reliant, frequently requiring support from others. Ultimately, digitalisation can also contribute to driving some people away from public transport. They might fall back on private means of transport, if available.

Because of the increasing use of digital technologies in public transport systems globally, we expect the results of this study to be applicable in other countries. Local context and cultural norms likely play a role, but we expect that our categories of difficulties and coping strategies can be transferred to other contexts to some extent. The same goes for our proposed model of coping. Besides, researchers who would like to investigate the impacts of digitalisation in transport services among so-called 'vulnerable groups' in a given context can get inspired by the methods described in this study.

So far, we have scarcely mentioned policy implications of this study. This is because our primary goal was to shed light on the mechanisms of digital inequality in public transport. Nevertheless, this study demonstrates the usefulness of actions to mitigate digital inequality. While formal and informal support systems are important, they are not available to everyone. Furthermore, there are also flaws in the support that people can get from the transport system. Thinking about solutions to mitigate digital inequality in transport services requires a broad reflection, one that touches design, governance and more – beyond the transport system itself. Therefore, we suggest further research into solutions to mitigate digital inequality in public transport and in other (urban) transport systems. This is a task we have taken up as part of a follow-up of this study (see Chapter 5 of this dissertation), and we would like to encourage others to do so as well; sources of inspiration here are Kolotouchkina et al. (2022) and Lam and Ma (2019), among others. Based on the results of this study, it seems likely that policy actions

to mitigate digital inequality in transport services will need to look into multiple perspectives. For instance, setting up programs to teach digital skills applicable in transport will likely not reach everyone, and complementary approaches will be needed.

Last but not least, this study can inspire researchers wishing to investigate the access to and use of shared mobility services among populations likely to be impacted by digital inequality. Their ‘digital only’ type of access poses new challenges (see Butler et al. (2021); Groth (2019); Vecchio and Tricarico (2018)), which will become particularly relevant should these modes become more mainstream.

Chapter 5: Fostering an inclusive public transport system in the digital era: An interdisciplinary perspective

In Chapters 2, 3 and 4, we saw that not everyone has the same possibilities to engage with digital tools to travel. Such differences tend to be patterned along the lines of existing disparities, such as socioeconomic disparities. As such, digital transformations may complicate mobility and hinder individuals' possibilities to access locations. Besides, the contemporary expectation for everyone to carry a smartphone and be skilled enough to use it puts those (temporarily) without (the required hardware/skills) at a disadvantage. The study in this chapter presents an overview of measures to mitigate the potentially exclusionary effects of digitalisation in public transport. It relies on interviews with experts working either in the public transportation sector or in other relevant sectors, hence the interdisciplinary perspective.

This chapter begins with an introduction section (5.1), followed by a description of the followed method (section 5.2). Section 5.3 describes our results: fourteen measures split up across five perspectives. We then present an outlook in section 5.4. We finish with conclusions in section 5.5.

This chapter is based on the following article:

Durand, A., Zijlstra, T., Hamersma, M., 't Hoen, A., van Oort, N., Hoogendoorn, S. & Hoogendoorn-Lanser, S. (2023). Fostering an inclusive public transport system in the digital era: An interdisciplinary approach. *Transportation Research Interdisciplinary Perspectives*, *22*, 100968. DOI: 10.1016/j.trip.2023.100968

The data that support the findings of this study contain information that could compromise the privacy of research participants and are therefore confidential.

5.1 Introduction

In today's society, people are often expected to show self-reliance (Keizer et al., 2019). This means that they are expected to keep up with a fast-paced society and take appropriate action by themselves when needed. This trend has been reinforced by digitalisation, as digital technologies play a key role in shaping societal expectations (Swierstra, 2015). One field where digital technologies have become particularly pervasive is public transport (PT). For instance, smart cards and smartphones have replaced cash and paper tickets in just a few decades (Brakewood et al., 2014; Golub et al., 2022).

Yet some (groups of) citizens are vulnerable to the increasing expectation to take care of everything by themselves digitally (Keizer et al., 2019). This is true for public transport too. In Germany for instance, 24% of the population reports feeling very limited in their local travels because of a lack of digital skills (Goodman-Deane et al., 2021). Digital skills usually refer to both medium- and content-related digital competences (Van Dijk & Van Deursen, 2014). There is no widely agreed definition of what it means to have 'low digital skills' in the context of mobility, but constantly needing assistance or a low performance on basic medium-related tasks like going back to a previous screen are usually seen as signs of low digital skills (Durand et al., 2023c; Goodman-Deane et al., 2021) (Durand et al. (2023c) refers to Chapter 4 of this dissertation).

There are multiple and sometimes overlapping groups of individuals who are more likely to be negatively impacted by pervasive digitalisation in public transport: older adults, people with a lower education level, people with a lower income, migrants and people with learning and communication issues (Durand et al., 2022) (Chapter 3 of this dissertation). Yet public transport may be crucial to some of these individuals, notably due to the reduced access to driver's licence and/or cars among these groups (Bigby et al., 2011; Ryan et al., 2015; Witte et al., 2022).

Interviews with individuals who are more at risk of digital exclusion in transport have revealed that many experience difficulties with digitalisation in public transport to some extent (Durand et al., 2023c). They tend to rely heavily on their social network to help them navigate the public transport system. When support is neither available nor sufficient, they may disengage from using public transport altogether. As such, digitalisation can result in an unequal access to public transport; this has been coined *digital inequality in public transport* (Durand et al., 2022). In an inclusive society where public transport is a public service, this is an issue that needs to be addressed.

Tackling difficulties stemming from digitalisation is a relatively new task for transport practitioners and policymakers alike (Macharis & Geurs, 2019), unlike issues linked with physical and sensory accessibility. Nowadays, many public transport professionals are familiar with ways to enable barrier-free travelling for people with a physical or auditory impairment. From lifts at stations to level access and auditory guidance, best practices have been shared within the sector for decades already (European Commission, 1999; European Railway Agency, 2015; United Nations Development Programme, 2010). Examples of improvements can be found in the Netherlands (ProRail, 2021) and in Japan (Dobashi & Ohmori, 2018).

As digital developments in public transport have taken place at a fast pace (Van Dijck et al., 2018), we lack an understanding of solutions to tackle the accessibility issues these developments are causing. At best, fragmented responses are put forward. For example, a large inventory of barriers to plan and deploy inclusive digital mobility services in Europe shows that some services do take into account digital accessibility for people who are visually impaired (Delaere et al., 2021). However, people with different needs, e.g. due to lower digital skills, are seldom considered. At worst, policymakers and practitioners may not respond at all.

Nevertheless, there are other sectors with a somewhat more mature understanding of the ins and outs of pervasive digitalisation. For instance, exclusion due to digitalisation has been on the radar of health and public administration professionals for decades (Ranchordás, 2022; Saeed & Masters, 2021; Sarkar et al., 2011). Besides, communication science researchers have put forward frameworks to mitigate digital inequality and foster digital inclusion (Asmar et al., 2022; Goubin, 2015; Mariën & Van Damme, 2016; Van Dijk, 2019). We suggest that the transport sector should not reinvent the wheel, and learn from these initiatives.

In this study, we are focusing on actions that can be undertaken to foster inclusion in public transport in the digital era. This means mitigating digital inequality in the present, and making sure that such efforts are sustained in a future where digitalisation will likely keep evolving and playing an important role (Bonnetier et al., 2019; Canzler & Knie, 2016). Such actions therefore also contribute to making public transport more accessible to a larger group of (potential) users, and not only to people who are currently less digitally self-reliant – i.e. people who mostly rely on others to help them navigate digital services, or avoid digital services at all costs.

The present study pieces together existing initiatives and lessons learnt in the transport sector itself, and takes inspiration from research and best practices in other fields. The research took place in the Netherlands, where the public transport sector has been actively leveraging on the opportunities offered by digitalisation (Council for the Environment and Infrastructure, 2021; Government of the Netherlands, 2021). The national rail network is operated by a public limited (or 'publicly tradable' in U.S. terms) company (NS), with the state of the Netherlands as the sole shareholder. The government also contracts out various regional and local public transportation services (bus, metro, tram and a few train lines) to other companies. Some of these companies are also public limited companies with a large municipality as sole shareholder, and others are private-sector companies. Despite its limited geographical scope, we argue that this study offers relevant insights for international policymakers and practitioners alike wanting to ensure an inclusive offer of their (public) transport services in the digital era. We aim at answering the following question: *What are possible policy approaches to mitigate digital inequality in public transport in the Netherlands?*

To the best of our knowledge, no publication examining such policy approaches for the field of public transport exists yet. Our main approach to answer this research question consisted of interviewing a diversity of experts, both in the transport sector and outside. We used a framework from communication science research in order to organise both our analysis and our results. This study is also informed by international literature and insights from interviews with

people at risk of digital exclusion in public transport, described in Durand et al. (2023c); see section 5.2.3 for a description of our triangulation process.

5.2 Methods

5.2.1 Analytical framework and data collection

Our primary information source to answer our research question consisted of interviews with experts. The first condition that guided our sampling process was that experts should have some affinity with accessibility or inclusivity themes, and experience on and knowledge about either digitalisation in public transport, or outside the transport sector. With this condition, we ensured that there was a certain homogeneity within interviewed experts. Homogeneity is important to keep the scope sharp and be able to detect pattern in the data (Guest et al., 2006).

We added a second condition to our sampling process. Indeed, we needed a certain diversity in expertise as we aimed to outline the multidimensionality of perspectives to address digital inequality in public transport. For this reason, we used a framework to guide us, namely Van Dijk's (2019) policy perspectives on how to solve digital inequality (see Table 5.1). Van Dijk is known for his work around digital inequality, in particular his causal and sequential model of digital media access (Van Dijk, 2005). See Durand et al. (2022) for how this model can be used to understand and study digital inequality in the context of transport services (Chapter 3 of this dissertation). Ever since Van Dijk described this theory, he has linked policy perspectives to it (Van Dijk & Hacker, 2003). The third column of Table 5.1 links his policy perspectives to his model. When reaching out for experts, we first estimated which perspective(s) they would most likely put forward based on their previous body of work. This helped us to ensure that we would talk to a diverse pool of experts. For example, our results would have been particularly biased in one direction if we had only talked to experts focusing on an educational approach to mitigating digital inequality.

The interviews were conducted over the course of multiple months, which left us time to analyse the added value of each new interview and assess whether we had reached a point of saturation, 'the point in data collection and analysis when the new information produces little or no change to the codebook' (Guest et al., 2006, p. 65). In total, we interviewed eleven public transport experts with experience on and knowledge about digitalisation in public transport, and with some affinity for accessibility or inclusivity. These experts were from policy, academia, research institutions, transport operators and digital service providers. The amount of PT experts with some affinity for accessibility or inclusivity we interviewed was limited by the amount of suitable candidates in general (Gläser & Laudel, 2010). We also interviewed eleven experts on digitalisation outside the transport sector. These were experts on digital inclusion in general, in the healthcare sector or in public administration services. Two of these experts were working in Belgium and not in the Netherlands, but with previous work experience in the Netherlands and extenstive knowledge of the Dutch context. Besides, interviewing experts who are familiar with practices in another country (here, Belgium) can be enriching for the study. These interviews with experts outside the PT sector aimed at getting insights into and concrete examples on how

other sectors are tackling digital inequality. The list of organisations where these experts came from, as well as the roles and experience of these experts, can be found in Appendix D.

We conducted semi-structured interviews for both sets of experts in 2020 and 2021, lasting between 40 minutes and 1h30. The exact questions varied per expert as we approached them with some prior knowledge about their previous work. In general, the interviews revolved around the following three main topics:

- Role of digitalisation in their field (public transport, healthcare, public administration, … depending on the expertise of the interviewed expert) and developments over the past few years (such as public policies).
- Issues around pervasive digitalisation in sector, particularly in relation to a lack of accessibility and exclusion for users.
- (Possible) solutions and lessons learnt from what works and does not work.

Note that the framework of Van Dijk serves as a starting point: since we focus on tackling digital inequality in public transport in particular, our final perspectives are bound to be somewhat different from the ones presented by Van Dijk (2019). For instance, we estimated from the start that the technological perspective as described by Van Dijk (2019) would likely not be relevant for this study. Providing access to a smartphone can be a potentially effective approach to tackle digital inequality, but it is a generic solution that transcends actors in the public transport sector.

Table 5.1: Policy perspectives on digital inclusion, from Van Dijk (2019).

Perspective	**Goal**	**Focus on**
Technological	Creation and distribution of digital technology	Physical access
Economic	Support market, competition and innovation	Physical access Collective usage
Educational	Formal and adult education of information and communication technologies	Digital skills
Social	Inclusion and participation of all	Individual usage
Persuasive	Awareness	Motivation and attitudes

5.2.2 Data analysis

In order to determine measures to mitigate digital inequality from our expert interviews, we analysed them in a structured way. We had the interviews transcribed and we subsequently uploaded them in a qualitative data analysis programme, ATLAS.ti 9. We used qualitative content analysis as described by Kuckartz (2014). Our choice of this type of analysis was motivated by two reasons. First, we were specifically looking for a category-based method, where ‘the analytical categories are the focus of the analysis process’ (Kuckartz, 2014, p. 68). Second, we wanted to select a type of analysis suitable for practice-oriented data such as our expert interviews. In fact, other researchers have used this type of analysis for expert interviews (see e.g. Zerwas (2019)). The first author was the main analyst and shared and discussed findings with co-authors regularly during the analysis period. This was done to ensure confirmability of the results, i.e. the extent to which the study's findings are supported by the

data (Shenton, 2004). Note that all interviews were done with two interviewers, the first author with one co-author.

We conducted the analysis as follows. To begin with, we coded text sections where experts were mentioning potential solutions to mitigate digital inequality in public transport. During our second and third coding rounds, we applied respectively deductive and inductive approaches. In the second coding round, we gathered our initial codes into one or multiple of Van Dijk's (2019) proposed policy perspectives. Since not every proposed solution fitted within those perspectives, we developed two new perspectives in the third coding round. Then, in a last coding round, we further refined our coding system. That meant grouping solutions into non-overlapping categories we labelled "measures". We also decided upon one dominant perspective for each measure. We did so for the sake of communication simplicity towards public transport professionals and policymakers.

5.2.3 Triangulation of results and respondent validation

To ensure that our results were as valid and complete as possible, we used two techniques. Firstly, we used triangulation of data. This means using more than one method to gather insights on the same topic. This is a common practice in qualitative research (Flick, 2009), meant to to enhance both the dependability and the credibility of the study results (Fusch et al., 2018). In addition to expert interviews, we collected insights from literature and interviews with individuals at risk of digital exclusion in public transport. See Durand et al. (2023c) for the description and analysis of interviews with individuals at risk of digital exclusion in public transport; note that these were both users and non-users of public transport. Triangulation also allowed us to extend our understanding (Ritchie & Lewis, 2003) of measures to mitigate digital inequality in public transport.

Secondly, we verified our measures and perspectives through respondent validation (Ritchie & Lewis, 2003). That way, we controlled that we had not missed out on measures and that our list of possible measures made sense, thereby enriching the credibility of our results (Birt et al., 2016). Here, we used a two-step approach. The first step consisted of presenting our results to an expert on digital inequality and digital inclusion previously interviewed. This expert was invited to extensively reflect on our suggested perspectives and measures. The second step consisted of a 2-hour online workshop organised in April 2021 with 20 Dutch public transport experts. They represented 10 different organisations in the Netherlands, from policymakers of the Ministry of Infrastructure and Water Management to public transport authorities and operators (see list in Appendix D). After a general introduction, four of the authors of this study led a structured discussion in two separate breakout rooms. A few of these experts or colleagues of these experts had been previously interviewed. Not only did this session allow us to get feedback on our preliminary results, it also enabled us to deepen our understanding of the barriers to apply certain measures.

5.3 Results

In this section, we present the results of our analysis. We uncovered fourteen measures, categorised into five perspectives. Three perspectives are directly translated from Van Dijk's framework. As expected, our interviews did not reveal that the technological perspective would be directly applicable to the transport sector. For instance, none of the experts, even those outside the transport sector, suggested that giving access to a smartphone to people would be helpful to foster inclusion in public transport in the Netherlands. Similarly, neither the expert or the (non-) PT users, nor literature showed evidence that the economic perspective – solving problems 'through a better supply of digital technology' (Van Dijk, 2019, p. 136) – would directly contribute to mitigate digital inequality in public transport. However, experts frequently emphasised the importance of a good design of digital technologies and services. This is why we created a new perspective: the *design perspective*.

Besides, experts often highlighted solutions on a higher level than the educational, social and persuasive perspectives showed in Table 5.1. These solutions do not directly impact individuals. Instead, they are focusing on securing the commitment to addressing the unequal access to public transport due to digitalisation now and in the future. We named this a governance perspective. Experts outside of transport often put this perspective forward, as we reflect on in section 5.4.4.

These five perspectives and their corresponding measures are summarised in Table 5.2. The last column indicates the amount of experts who put forward the various measures; this demonstrates the great complementarity of having interviewed experts both in the public transport sector and outside (see also section 5.4.4). The remainder of this section describes each measure.

Table 5.2: Summary of the proposed perspectives and measures to foster digital inclusion in public transport.

Proposed perspectives	**Suggested measures**	**Amount of experts who put some version of this measure forward**	
		PT experts (11 in total)	**Experts outside PT sector (11 in total)**
Design perspective	#1 Ensure a usable design and strive for a Universal Design	4	9
	#2 Involve user groups in the design of digital products and services	5	6
	#3 Use assessments and standards	1	6
	#4 Create more awareness among designers and developers	2	1
Educational perspective	#5 Provide courses to improve digital skills with an application in public transport	2	8
	#6 Train public transport staff	1	4
Persuasive perspective	#7 Raise awareness on the positive outcomes of digital tools in public transport	2	3
	#8 Communicate clearly	3	5

Social perspective	#9 Provide non-digital alternatives and safety nets	6	10
	#10 Dedicate special attention to hard-to-reach groups	4	9
	#11 Make use of specialist products	5	2
Governance perspective	#12 Monitor developments and support research	2	8
	#13 Build reflexivity	1	6
	#14 Adopt a proactive long-term approach	2	6

5.3.1 Design perspective

The design perspective consists of aiming at an accessible design of digital products and services from the start by involving various groups of potential users. Experts also put forward the necessity of embedding an 'accessible design thinking' within the transport system itself.

Measure 1: Ensure a usable design and strive for a universal design

Experts all agree that a prerequisite for an inclusive digital product or service is that it should have a usable design. Based on Shneiderman (1980) and Nielsen (1994), Van Dijk (2019) defines the usability of a digital product or service as the combination of multiple characteristics. These characteristics include the ease of accomplishing a basic task, how quickly this task may be performed, how easy it is to remember how to carry out a task, the extent to which mistakes can be corrected, the pleasure of using the digital tool and how intuitive its use is. Ideally, the use of the service or product should not depend on the level of skills of users. Customising which functionalities are visible or hidden in an app is a way to cater to users with a wide range of digital access (Fuglerud, 2014). Although not strictly part of usability, experts stressed the importance of a design that would respect the privacy and personal data of users. In addition, design needs to be adaptable, as the needs of users are not static but change over time (Patrick & Hollenbeck, 2021).

Working with Universal Design (UD) principles was suggested by a few experts. These principles include usability characteristics and go beyond as they are concerned with addressing the needs of 'all people, to the greatest extent possible, without the need for adaptation or specialized design.' (Connell et al., 1997; Story, 2001). The EU-funded INDIMO project has put forward an extensive UD manual for digital products or services in mobility, applicable in Europe and beyond (Di Ciommo et al., 2021; INDIMO, 2022b). Having a design useful to people with diverse abilities – the equitable use principle – plays a central role in UD.

Measure 2: Involve user groups in the design of digital products and services

In line with UD principles, there is a wide agreement in literature and among experts that involving diverse groups of users as early as possible in the design process of a product or service is an essential condition to making it inclusive (Bonnetier et al., 2019; Di Ciommo et al., 2021; Goubin, 2015; Henni et al., 2022; Mariën & Van Damme, 2016). For instance, this

could mean asking explicitly older adults from 65 to 90 years old and people with lower literacy levels to be involved in the early design stages of a ticket vending machine. Involving these groups is not only about asking them what they want: it is about organising digital tools around how end users make decisions and process information. A design that is accessible for those having the most difficulties, is likely to be inclusive to almost everyone.

When diverse groups of users are not involved early on – or not at all – the design process will often result in specifications for the mainstream user (Bonnetier et al., 2019; Gill et al., 2007). In theory, these specifications can be modified later on. In practice, this often turns out to be expensive, long to carry out, or simply impossible (Bekiaris et al., 2009; Davis & Nathan, 2015). For instance, Van Kuijk et al. (2014) argue that too little attention has been given to users in the development of the Dutch public transport smartcard system. Some adaptations have been carried out since its implementation to make the card more accessible, but at a cost and over multiple years.

Nevertheless, early user involvement also comes with issues. One of them is that people may have internalised stereotypes pertaining to their age, abilities or gender, jeopardising their ability to state their needs (Vermeij & Hamelink, 2021). This is why involving professionals who are in contact with these groups can also be helpful. According to the experts in digital health services we interviewed, involving social workers, nurses and doctors adds value in the design of e-health services. Indeed, they have some understanding of the needs of end users and they need to be able to explain to them how to use the final product. In public transport, this means that public transport staff but also care coordinators and key contact persons representing groups of end users could have a role to play in the design of digital services, as put forward by Bonnetier et al. (2019) in Belgium.

Measure 3: Use assessments and standards

Under the European Accessibility Act (EAA), service providers such as public transport operators will be required to meet certain standards for digital accessibility from 2025. Websites, mobile services, electronic tickets and information from operators will be covered by this law (European Commission, n.d.). This Act is supposed to cover people with physical or sensory impairments as well as people with autism or dyslexia, mild intellectual impairments and impairments due to old age.

Digital accessibility standards are not new. An EU-wide digital accessibility legislation for websites was adopted in 2016 (European Commission, 2022b). Experts on the accessibility of governmental websites highlighted that a positive approach usually works best when service providers are required to improve the accessibility of their services as a compliance-based approach can be counterproductive – organisations would do the bare minimum. This means using assessments to prepare the transition to an accessible and inclusive service: what are the operators or service providers already doing well? Who is doing best? Such an approach can stimulate the ones lagging behind. Assessments are also deemed particularly useful by interviewed experts because they can challenge providers beyond accessibility standards.

Indeed, a service can be accessible yet not inclusive. Accessibility usually focuses on the needs of people with impairments (Emiliani, 2009) and can be objectively measured. Inclusivity goes one step further: it is about taking into account the whole diversity of end users (Fuglerud, 2014; Waller et al., 2015), and providing a range of features that the end user can choose from to fit their needs in their context (Patrick & Hollenbeck, 2021).

Although legal instruments that enforce or encourage digital accessibility are emerging, most of the rules do not actually specify the elements expected in the accessibility (Di Ciommo et al., 2021). Nevertheless, multiple tools for assessing the accessibility and inclusivity of digital products and services in mobility have been published in recent years as part of EU-funded projects (INDIMO, 2022a; Nesterova et al., 2020; Repetto & Bagnasco, 2021) and outside these projects (Dadashzadeh et al., 2022; Richardson et al., 2022). They ask questions such as the possibility to use non-digital alternatives, text-to-speech technology support, the possibility for user feedback, etc.

Measure 4: Create more awareness among designers and developers

Raising awareness among designers and developers about the specificities of people that fall outside a certain 'standard user range' can encourage a more inclusive design. Trainings or games exist for this purpose at all levels, starting with design and engineering students as Tüker and Çatak (2020) propose in Türkiye. Furthermore, an interviewed expert explained how accompagnying someone during their journey can be eye-openeing. Such an experience had shown her the challenges people may face in public transport.

Diversifying the profiles of designers and developers can also increase the inclusivity of digital technologies. No technology is ever value-neutral (Van Den Hoven, 2012); it is laden with (implicit) assumptions from its creators. For instance, Rosales and Fernández-Ardèvol (2020) showed that digital platforms often embed ageist values, i.e. values that discriminate based on age. This is due to a lack of (age) diversity in innovation teams, as also recognised by a few interviewed public transport experts. Design decisions tend to follow homophilic patterns, arising from a shared background, such as education, language and socialisation practices (Rosales & Fernández-Ardèvol, 2020). Such a lack of diversity enhances the need to involve (potential) user groups early on (measure 2) (Bonnetier et al., 2019) and to compensate them fairly for their expert knowledge.

5.3.2 Educational perspective

The educational perspective focuses on people with lower digital skills and how they can be best assissted when needed.

Measure 5: Provide courses to improve digital skills with an application in public transport

This measure focuses on training individuals' digital skills with an application in public transport. Olausson and Kamel (2020) give the example of a Swedish regional public transport authority and operator organising training events for older adults every year. According to a

representative interviewed by Olausson and Kamel (2020), these events are highly appreciated by both participants and operators. In France, the public transport administration in Paris (RATP) is provinding mobility workshops for various target groups, which usually include a digital component (RATP, 2016). Nevertheless, such initiatives have been discontinued in the past in the Netherlands. According to experts, quantifying the effectiveness of such trainings and finding the right target group were the two main issues. Regarding the latter, an interviewed public administration expert made a suggestion: in the Netherlands, some public administration services may offer individuals calling these services the possibility for a referral to free courses to improve their digital skills. According to this expert, about 11% of such calls result in a referral. Staff training to discern relevant individuals is important (see measures 6 and 7).

Ultimately, literacy and basic digital skills play an important role in being able to develop new digital skills (Van Dijk & Van Deursen, 2014). Ideally, trainings to improve digital skills with an application in public transport should be linked to existing initiatives, for instance in the field of adult education or broader digital skills trainings. In the Netherlands, some general digital skills courses have started including a part on planning a public transport trip in their standard offer (see Digisterker (2020) for instance). Importantly, such trainings need to have a practical component (Harvey et al., 2019). A few individuals interviewed in Durand et al. (2023c) reported having taken part in general courses to improve their digital skills. Those who could benefit from on-hands support from family or friends to help them apply their new knowledge had seen a positive impact of the course on their ability to plan trips independently, while the others had not.

Measure 6: Train public transport staff

Digitalisation also affects staff. Workers play a key role in making digital transformations more inclusive. This has been documented in the healthcare sector for decades (Kruszyńska-Fischbach et al., 2022). Interviewed experts in healthcare argue that the public transport sector is no exception as public transport staff are in contact with travellers. As such, they play an important role in shaping travellers' experience with digital technologies, particularly for those who are less digitally self-reliant (Bigby et al., 2019; Van Holstein et al., 2021). The interviews conducted in our previous study show that PT staff can have a significant impact on travellers who are less comfortable with digitalisation. For instance, they can facilitate travel by helping with seemingly small but impactful actions, such as requesting a smartcard or activating an option on a travel app (Durand et al., 2023c).

Public transport workers could be trained to recognise the barriers that certain groups of travellers face when using digital tools, as well as the possibilities to overcome these barriers. This is currently not the case in the Netherlands. Some interviewed PT users reported instances when staff had refused to help them, wrongly assuming that they had access to digital travel information (Durand et al., 2023c). Increasing the digital skills of public transport workers themselves may also be needed, but there needs to be a clear scope of what falls under their competences or not (Voss & Vitols, 2020).

5.3.3 Persuasive perspective

The persuasive perspective is about enticing people to use digital products and services by making them more appealing. An inclusive design is important here (Rathenau Institute, 2017), as well as a couple of additional measures.

Measure 7: Raise awareness on the positive outcomes of digital tools in public transport

Campaigns and awareness programmes can trigger interest in using digital products and services in public transport. The interviews conducted in Durand et al. (2023c) reveal that people with a lower digital self-reliance can also reap benefits of digitalisation. By highlighting the advantages of using such digital tools, such interventions can motivate individuals who do not usually turn to digital services and products to give them a try.

These campaigns can also target people who are more digitally self-reliant, by encouraging them to be more open to assist others when needed (Bigby et al., 2019; Sabie & Ahmed, 2019). A more personalised approach consists of mobilising public transport ambassadors (usually peers) (Janse, 2012; Leliveld, 2022) or coaches for people with an impairment. Both have the opportunity to raise awareness about the benefits of digital technologies in a tangible way and boost confidence of people with a lower digital self-reliance. Experts noted the need for subsidies for both of such interventions; see the Outlook section below.

Staff can also play a role in raising awareness. They can entice travellers who use service desks or who call to use online services by explaining and showing them the added value of online channels (Goubin, 2015). However, this needs to be done carefully, or it can have the opposite effect as a few experts cautioned. For example, many PT users with a lower digital self-reliance interviewed in Durand et al. (2023c) mistakenly believed that some analogue services and products had disappeared. The art is to ensure that people do not feel pressured to use digital services (Pieterson, 2009).

Measure 8: Communicate clearly

Communicating clearly in accessible language is an absolute precondition to allow people to engage with digital products and services (Mariën & Van Damme, 2016). In general, the use of plain and everyday language, icons and a clear layout are all recommended (Goubin, 2015; Hueting et al., 2021). In non-English speaking countries, English technology jargon may not suit an accessible text; even in the UK, Harvey et al. (2019) reported that a term like 'smartphone' is often unsuitable for an older demographic. In the Netherlands, language ambassadors help public administration services write more accessible and clearer texts on their websites (Pander Maat & van der Geest, 2021). Using the langage level B1[13] is often advised in some countries (DELF-DALF, n.d.; Government of the Netherlands, n.d.). Experts outside the public transport sector also emphasised that alignment between sectoral stakeholders

[13] The B1 language level refers to the Common European Framework of Reference for Languages (CEFR) level B1, an intermediate level of language proficiency (Council of Europe, n.d.).

regarding communication and terms used via digital channels is crucial to entice people into using these channels.

5.3.4 Social perspective

The social perspective aims at a full access of public services – such as public transport – for everyone.

Measure 9: Provide non-digital alternatives and safety nets

Non-digital alternatives may be precisely what allows people to travel independently, as showed in Durand et al. (2023c) in the Netherlands and Van Holstein et al. (2021) in Australia. As part of a social perspective, maintaining them makes sense. For the operator, this measure often means retaining analogue options such as paper tickets or service desks, but also public transport staff. Interviews with non-PT users with low digital skills show that they find it hard to imagine using public transport without having PT staff available to answer their questions (Durand et al., 2023c). Interviewed public transport experts also supported the fact that help from PT staff can be instrumental for small, one-off actions as mentioned in measure 6.

When non-digital alternatives are retained, it is essential to ensure their quality. Otherwise, they lose much of their usefulness (Mariën & Van Damme, 2016). Neverthless, public transport experts are not always in agreement about how this translates in real life. Some deem that retaining a customer service phone number for which individuals have to pay extra charges is questionable. Others justify such a fee by emphasising the high maintenance costs of non-digital alternatives.

Experts and literature mentioned ways to ensure quality non-digital alternatives under the constraint of costs. We list them below (this list is not exhaustive and is in no particular order):

- Classifying tasks in terms of urgency, complexity and audience to decide on the usefulness of analogue alternatives (Goubin, 2015). Research on digital transformations in public administration services shows that older adults, people with cognitive impairments and people with financial difficulties tend to value human contact more (Ebbers et al., 2016). Pieterson and Ebbers (2020) have also demonstrated that people usually feel best served through non-digital channels when complex questions are involved or quick responses to important matters are needed. A public transport expert confirmed this: in times of disruptions or strikes, up to three times more individuals than normal call the information service line of a large Dutch multimodal travel app/website. Besides, these individuals tend to be more diverse in terms of demographics than usual.
- *When appropriate*, directing people to digital options (see measure 8).
- Using low-tech tools such as help buttons on ticket vending machines to assist users remotely. Visual contact with an assistant, via a screen on vending machines, can give people reassurance.

- Bundling non-digital services of various parties. This approach lies at the core of the Digital Inclusion programme launched in 2018 by the Dutch Ministry of the Interior and Kingdom Relations. Citizens can visit the Digital Government Information Points present in almost all Dutch libraries if they have difficulties with any digital public administration service.

Some experts also highlighted that digital technologies are not infaillible. Analogue alternatives can also be important for digitally self-reliant travellers in case of technical failures. Besides, smartphones can also run out of battery or have network issues; free and public internet as well as public charge points act as safety nets in such cases (Golub et al., 2019).

Measure 10: Dedicate special attention to hard-to-reach groups

Dedicating special attention to hard-to-reach groups means investing in coordinated actions to support the needs of particular groups that other measures may not reach. This measure explicitly acknowledges the need for partnerships, for instance between local policymakers, libraries, community centres, non-profit organisations and social workers. Mariën and Van Damme (2016) emphasise that creating partnerships between parties is an essential building block to foster inclusion in an increasingly digital world. Parties that are closest to particular groups will understand their specificities better, such as social workers and community centre coordinators (Durand et al., 2023c). These parties will also be more easily able to reach them (Van Dijk, 2019). Outside the transport sector, an example of such measure would be the Digital Government Information Points (see measure 9) as described by an interviewed expert. In the field of public transport, an example of such measure would be a neighbourhood event advertised in the local newspaper and targeting a specific group (e.g. older adults). Such an event could aim at making this group more familiar with their transport options and answer questions they might have about e.g. how a smartcard works, which app to choose to look for travel information, etc. A more concrete example is that of maisons des mobilités (literally "mobility houses") in France: these are places being developed in rural and peri-urban areas particularly, offering support to travellers when needed (Losego, 2018).

Measure 11: Make use of specialist products

In some cases, specialist products – traditionally referred to as assistive technologies[14] – might be needed for individuals to be able to fully use and reap the benefits of digital technologies. Indeed, the goal of the Universal Design approach (see measures 1 and 2) that design should be such that no adaptation and specialised design is needed, is often not realistic (Emiliani, 2009). Instead, design professionals and researchers alike have been making the case for inclusive design (Fuglerud, 2014; Waller et al., 2015). Inclusive design considers the full range of human diversity such as ages, abilities and cultural background, and acknowledges this diversity as a

[14] Waller et al. (2015) suggest using the term *specialist products* instead of *assistive technologies*, for the latter is usually embedded within a disability-centric approach. Besides, they argue that nearly all technology can be considered as assistive anyway.

starting point in the design strategy. This is where specialist products can play a role. They can range from pieces of equipment to services or product systems including software (European Disability Forum, 2020). In the case of public transport, specialist products can be apps that focus on people with cognitive difficulties or with visual difficulties. The Dutch GoOV (GoOV, n.d.) and NS Platform Guide (NS, n.d.) apps are respective examples of such tools. Specialist products can also be non-digital, such as a helpline. According to Kok and Koopmans (2017), the need for specialist products even justifies the need to keep non-digital alternatives in public transport (see measure 9).

Interviewed experts highlighted the importance of two aspects when introducing specialist products. First, design and involvement of end users is key (see section 3.1) to ensure the success of specialist products. Otherwise, the product may be useless. This is what some transport experts reported, based on their experiences developing tools that ended up unused, namely a reading tool in a travel app and a Braille map. Second, these specialist products should be developed with a long-term perspective, they should be future-proof. In particular, one should be able to maintain them. Experience with the digitalisation of public administration services has shown that websites developed for people with specific accessibility needs (like eyesight issues) have often been poorly maintained. They were not regularly updated and became substandard and outdated versions of the original websites.

5.3.5 Governance perspective

Last but not least, we found a call among experts for (semi-)public organisations governing public transport to reappropriate themselves the governance of digitalisation in the sector. Literature also echoes this call (see e.g. Bonnetier et al. (2019) and Herzogenrath-Amelung et al. (2015)). Governance is essentially about steering the actions of a large group of people to achieve specific goals, and minimise risks and undesired outcomes (Hoppe, 2010). For this specific perspective, the involvement of experts on (the governance of) digitalisation from outside the transport sector was of particular added value. Indeed, they offered a middle road between technological fatalism on the one hand (‘good or bad, technology is coming and resistance is futile’) (Cohen & Jones, 2020, p. 81) and technological optimism on the other hand. The latter is rooted in the belief that everything is getting better for everyone thanks to digital technologies, and is usually driven by technology manufacturers and marketing discourses (Herzogenrath-Amelung et al., 2015; Steer, 2022). The measures presented in this perspective aim at securing the issue of unequal access to (public) transport due to digitalisation now and in the future at a decision-making level.

Measure 12: Monitor developments and support research

Experts in the healthcare sector and in public administration services agreed that monitoring is an important building block in the governance of digitalisation. Knowing what is going on in terms of digital developments, how (potential) users are affected and how existing policy goals are impacted is necessary to be able to contribute to steering digital transformations in the sector.

Investing in inclusive monitoring becomes capital to capture the experiences of people who are less digitally self-reliant. Therefore, relying exclusively on web-based panels and barometers is not enough.

Besides monitoring, research projects are also needed to better understand the ins and outs of digital transformations in the sector. A few interviewed experts highlighted the need for both quantitative and qualitative research on this topic (see also Mariën and Van Damme (2016)). When one focuses solely on quantifiable aspects, more subtle yet significant impacts might be overlooked. Swierstra (2015) call these 'soft impacts'. They are qualitative, co-produced by users and are invited, and not strictly speaking caused by, technologies. Soft impacts are about changing practices, such as the expectation from public transport staff that passengers have access to a smartphone (Durand et al., 2023c) or new forms of work for passengers and drivers caused by a cash ban on buses as Pritchard et al. (2015) investigated in the U.K.. By contrast, quantifiable impacts unequivocally caused by technology are 'hard impacts', such as economic impacts. In Swierstra's view, the ubiquitous and occasionally exclusionary nature of soft impacts means it is no longer acceptable to disregard them.

Measure 13: Build reflexivity

Digitalisation puts pressure on public values (Royakkers et al., 2018). This observation also applies in the transport system, where commercial interests can conflict with the societal interest in an inclusive mobility system (Council for the Environment and Infrastructure, 2021; Physical Environment Consultative Council, 2021). Just as measure 4 requires designers and developers to question their own assumptions, this measure asks institutions to be reflexive. Institutional reflexivity means that the organisation holds up a mirror to itself regarding its own activities, assumptions, how it deals with underrepresented voices (Young et al., 2019) and how it deals with public values (Stilgoe et al., 2013).

A way to build reflexivity is to give a permanent place to ethical reflections in organisations. This is precisely the message addressed by the Dutch Physical Environment Consultative Council to the Ministry of Infrastructure and Water Management after experimenting with ethical reflections on a few topics (Physical Environment Consultative Council, 2021). Ethical reflections, also called moral deliberations, originally come from healthcare (see e.g. Hermsen and ten Have (2005)). During such a reflection, participants share their perspectives and values, explore the implications of different courses of action, and consider the potential impacts for various stakeholders. The goal is to reach a deeper understanding of the ethical dimensions of a situation and to identify a course of action that is consistent with the participants' shared values and principles. A concrete example for an ethical reflection could be on whether it is desirable to add a premium on analogue alternatives like paper tickets.

Measure 14: Adopt a proactive long-term approach

This measure consists of establishing a long-term approach to managing digital transformations in public transport services. Some experts suggested working with tools associated with anticipatory governance, as Cohen and Jones (2020) also put forward. Anticipatory governance seeks to anticipate and respond proactively to potential future challenges and opportunities, rather than simply reacting to them after they have occurred. It involves using foresight, scenario planning techniques (see Snellen et al. (2019)) and 'what if' analyses (see Ravetz (1997)) to identify emerging trends and issues, and then designing policies and strategies to address them. Such tools can be used before technology is being developed, but anticipation processes can also be applied when technology is at the threshold of society. Although scenario planning does not provide a definitive blueprint for the future or prescribe specific actions, it does compel policymakers to approach evolving situations in a deliberate and systematic way, weighing their available responses (Cohen & Jones, 2020). In the United States, Kuzio (2019) showed how a few metropolitan planning organisations are taking into account social equity impacts of emerging technologies in their long-term plans. Recently, Kollosche and Uhl (2022) provided specific examples of scenario building for digital and inclusive mobility systems in four European cities.

5.4 Outlook: what to do now?

5.4.1 Commitments

The measures presented in this study are intended to be used as initial steps for stakeholders working on inclusive digital transformations in public transport services. For instance, designers of innovative payment methods in public transport can take advantage of checking the resources we mentioned in measure 3. Policymakers working on facilitating the emergence of Mobility-as-a-Service (MaaS) could benefit from the tools mentioned in the governance perspective.

However, commitment is needed in order for any of these measures to have an effect. Such a commitment could be at the level of a company, like an operator deciding to train their staff or develop more awareness among their app developers. Some operators explained that they were willing to invest in a more inclusive public transport offer to some extent, as they were aware that there are wider benefits than 'just' people with a lower digital self-reliance: more ease of use for occasional users, safety net when battery phone is dead, etc..

Yet professionals involved during the workshop argued that operators in particular were unlikely to have (enough) budget to properly address issues around digital inequality. A public transport system strongly oriented towards financial and economic efficiency offers little incentive to focus on people who are less digitally self-reliant. In general, experts contended that achieving changes to improve inclusion in public transport in the digital era may require a stronger, more fundamental commitment. Such a commitment could be a direct financial support (e.g. through subsidies) or could be directly built within concessions for a more structural engagement. For instance, authorities could include incentives and/or requirements

in contracts for concessions regarding standards for the provision of non-digital services. Note that this is already happening in the context of recent contracts for demand-responsive public transport services in the Netherlands and the UK (Potter et al., 2022; Reizen door Zeeland, 2023).

Such a commitment for an inclusive transport system could also be decided and legally anchored at a nation-wide level. For instance, the Dutch Ministry of Infrastructure and Water Management – responsible for transport issues – is now considering legally incorporating both the involvement of consumer organisations with expertise in PT accessibility in advisory processes as well as the use of the B1 language level for travel information (State Secretary of the Ministry of Infrastructure and Water Management, 2023). All in all, the measures described in this study can be used as valuable starting points when considering commitments for a more inclusive public transport system.

5.4.2 From accessibility to inclusivity

A way to ensure such a commitment to keeping public transport inclusive in the digital era would be to broaden the ongoing conversation around accessibility. In the Netherlands, public transport accessibility for people with physical or sensory impairments has been on the agenda of policymakers for decades (Spittje & Witbreuk, 2005). There is no denying that these groups deserve attention. Besides, they sometimes face problems due to digitalisation in public transport too (Vicente & López, 2010). Digital accessibility for these groups of people is increasingly taken into account, for instance via spoken instructions on ticket machines and the NS Platform Guide app (see measure 11) (ProRail, 2021). At the same time, if policymakers are striving for a fully accessible public transport system (see for instance action 17 of the Memorandum on the Future of Public Transport 2040 (Dutch Ministry of Infrastructure and Water Management, 2021) and the Agreement on Accessibility to Public Transport 2022-2032 (Dutch Ministry of Infrastructure and Water Management, 2022), broadening the discussion around accessibility to one on inclusivity would be a step forward. As previsouly mentioned in measure 3, accessibility usually focuses on the needs of people with impairments and can be objectively measured while inclusivity is about taking into account the whole diversity of end users. Such an observation about a narrow focus on (sensory and especially physical) accessibility is not exclusive to the Netherlands; see for instance the review of Levine and Karner (2023) about the narrow focus on mobility disability among transport planners in the U.S..

What makes such a shift challenging is that people with a physical or sensory impairment are usually easier to identify than people experiencing problems with digitalisation, and so are their needs. For instance, organisations for people with a visual impairment have become increasingly involved in the development of products and services in the public transport sector in the Netherlands. At the same time, there is no single organisation representing people experiencing difficulties with digitalisation and articulating their concerns. People facing issues with digitalisation in public transport consitute a heterogenous group and their needs are multifacted. For example, not all older adults face barriers due to digitalisation. As a result,

individuals struggling with digitalisation in public transport might become invisibilised, as Bonnetier et al. (2019) already warned in Belgium. This risk highlights once more the need for diverse user groups to be involved in the design of services and products, as presented in measure 2.

5.4.3 Complementarity of perspectives

Many of the measures we describe often refer to another one as a precondition. In fact, these perspectives arguably complement each other. We conclude, as Van Dijk (2019) does for digital inequality in a broder sense, that "all of these perspectives are necessary and valid; the digital divide problem is much too complicated to be approached with a single or limited strategy" (Van Dijk, 2019, p. 134).

Since difficulties around digitalisation in public transport are often measured in terms of digital skills of (subgroups of) the population, it can be tempting to focus solely on an educational perspective. However, such an approach reflects an overly narrow view of the issue of digital inequality (see Durand et al. (2022)). Besides, it is not viable to rely solely on courses without thinking about design, as technology keeps advancing. However, an inclusive design may never reach certain people without some degree or enticement and special attention to some groups (persuasive perspective). Since one functional design for everyone is likely irrealistic, specialist products, non-digital alternatives and staff training are probably needed (social perspective). And given that technology keeps evolving, securing the issue of unequal access to (public) transport due to digitalisation at a decision-making level makes sense (governance perspective). The "optimal combination" of measures will likely strongly depend on the situation and the target groups. There is no one-size-fits-all to mitigate digital inequality, as Yeboah et al. (2018) and Zhang et al. (2020) already highlighted.

5.4.4 Beyond the public transport sector

The measures presented in this study come at a cost and striving for the inclusion of every single person may be unrealistic. Since multiple sectors face similar issues around digitalisation, the (public) transport sector might benefit from joining nation-wide initiatives around digital inclusion, when they exist as they do in the Netherlands.

Importantly, there is only so much that the transport sector can address. If there is one point on which all experts agreed, it was that the transport sector cannot tackle digital inequality alone. Addressing more systemic issues that often underlie digital barriers like poverty and low literacy (see Durand et al. (2023c)) is also needed. This conclusion aligns with discussions on the need to view matters such as accessibility poverty and transport-related social exclusion – where digital inequality plays a role (Luz & Portugal, 2021) – through a wider lens of social and economic disadvantage (Lucas, 2012; Ward & Walsh, 2023).

At the level of our study, looking beyond the public transport sector itself proved beneficial. This study demonstrates the scientific and policy relevance of an interdisciplinary approach. A clear added value of involving experts from other fields is that they often had a more

overarching view of ways to mitigate digital inequality. They usually approach issues around (the risk of) digital exclusion from a more systems thinking perspective, with attention to feedback loops (unintended consequences), delays, the use of methodologies and by seeking collaborations. Notably, they generally explained the need for a governance perspective and possible actions to take in a more articulate way, reflecting a somewhat more mature understanding of the ins and outs of pervasive digitalisation. These experts usually had more work experience than the PT experts (see Appendix D). However, we do not believe that it is a coincidence or a bias, for the intersection of accessibility/inclusivity and digitalisation in PT remains a fairly recent field. Experts in digitalisation in the healthcare and public administration sectors also highlighted a valuable takeaway for this study, namely the need to take into account the role of staff in digital transformations. Still, public transport experts obviously had an important role to play in this study too. In particular, they had more understanding of barriers to fostering inclusion in public transport.

5.5 Conclusions and further research

This study presents an overview of approaches to foster inclusion in public transport in the digital era, motivated by a fragmented or sometimes inexistent understanding of how to address the social impacts of digitalisation in PT. Based on 22 interviews with experts, we conclude that there is no one-size-fits-all to foster an inclusive public transport system in the digital era. Nevertheless, this study showcases important building blocks to achieve a PT system that keeps welcoming even the least digitally self-reliant users. A focus on an inclusive design from the start, showing the added value of digital products and services, providing courses, specialist products and non-digital alternatives are all components that contribute to fostering a more inclusive PT system in the era of digitalisation. Importantly, the role of the public transport staff ought not to be underestimated by public transport authorities and operators. Workers at the interface between the system and users of the system play a key role in the digital transition. Last but not least, securing the issue of unequal access to public transport due to digitalisation at a decision-making level is essential: (semi-)public organisations need to reappropriate themselves the governance of digitalisation in the sector. Nevertheless, there is only so much that the transport sector can do. Tackling more systemic issues that often underlie digital barriers like poverty and low literacy is crucially relevant.

Despite its geographical scope, this study offers relevant insights for international policymakers and practitioners alike wanting to ensure an inclusive offer of their (public) transport services in the digital era. Indeed, digital inequality in transport services goes beyond the Netherlands (Durand et al., 2022) and the leading position of the Netherlands in terms of digitalisation in general and in public transport makes it an interesting case. This study also shows that triangulating a source of information (here interviews with experts) with other sources of information (interviews with users and literature) can lead to the production of rich insights into a specific topic.

We note two main limitations to our study. Firstly, we were not able to detail all of the ins and outs of every single measure in one study. Yet the crux of the matter often lies in the finer

particulars. For instance, Levine and Karner (2023) showed that a compliance-based approach – which forms a part of measure 3 – may be insufficient, misleading and even fail to understand the lived experiences of people. This pitfall was already mentioned by an expert. Simiarly, Levine and Karner (2023) warn that public engagement opportunities (measure 2) may be used more as a way to check a box than to allow people to have a meaningful impact on outcomes. Therefore, the implementation details of each of the measures need to be carefully examined before proceeding to applying them. Secondly, even though we have involved a diversity of experts, reached a saturation point and read studies across multiple disciplines, we cannot claim that our list of measures is exhaustive.

In this study, we have chosen to exclusively focus on public transport and have left out modes such as shared mobility modes. Nevertheless, multiple measures can be applied to a much broader set of transport modes. For example, monitoring the evolution and impact of technological developments (measure 12) is not limited to traditional public transport services; it is arguably particularly relevant for emerging transport modes such as shared cars, shared scooters and shared bicycles. Our study can inspire researchers and professionals working on the potential deployment of these modes to examine ways to foster an inclusive access to these modes too.

While a strong point of this study lies in showcasing the breadth of actions that can be can undertaken to foster an inclusive public transport system in the digital era, the lack of knowledge on the efficiency of these measures can hinder their application. As underlined in measure 12, knowledge is essential to contribute to steering digital developments; further research could therefore focus on evaluating the impacts of measures that aim at mitigating digital inequality in transport services.

Chapter 6: Conclusions and recommendations

This dissertation sheds light on the process of access to and engagement with digital technologies in public transport, and establishes relevant determinants. It also identifies how digital transformations can potentially lead to exclusionary effects, and highlights approaches to mitigate these effects. This research contributes to the growing body of literature on transport disadvantage and transport equity by advancing the knowledge on barriers to travelling raised by digitalisation. By using a mix of qualitative and quantitative methods, this dissertation provides rich insights into the consequences of pervasive digitalisation in public transport. Contrary to the dominant narrative in transport research that digitalisation is and will be beneficial, we show that digital transformations can also complicate mobility and hinder accessibility of locations. Nevertheless, there are ways to ensure that current and future digital transformations will be more inclusive. Many of the insights from this research were gleaned in the context of the Netherlands but can also be generalised to other contexts. In this chapter, we synthesise the key findings from the research, discuss our results and how they can be generalised, elaborate on implications for practice and directions for future research.

6.1 Main findings and conclusions

Digital technologies can constrain access to public transport for some individuals who may already be disadvantaged, and even hinder it altogether. This becomes especially problematic when digital transformations are ubiquitous, but there are ways for decision-makers and practitioners to foster an inclusive public transport system in the digital era. Based on the research undertaken, we provide answers to the four research questions formulated in section 1.3. By answering these questions, the overarching goal of this research has been fulfilled.

6.1.1 How do car and public transport users access and engage with digital technologies for travel-related purposes, and to what extent do they perceive them to be necessary? (Chapter 2)

As the offer of digital services in transport expands, understanding users' digital engagement is important to make informed policy decisions. We lacked an understanding of how both PT (public transport) and car users engage with digital technologies and perceive them to be necessary to travel. This study has bridged this gap, using a 2022 survey of representative samples from both populations in the Netherlands.

Access and engagement with digital technologies

An equal proportion of car and public transport users in the Netherlands commonly used some form of personal digital tool to access travel information before or during their trip in 2022 (96%): a smartphone, a tablet, a laptop/PC/desktop or a navigation system. Car travellers use less frequently smartphones than public transport travellers (74% versus 90%), as the former are less reliant on this device: many cars are equipped with a navigation system nowadays. The proportion of people not relying on digital travel information at all has reduced from 10% to 4% between 2018 and 2022.

At least 10% of car and public transport users struggle with various aspects of digital skills applied in transport. Self-reported digital skills among public transport users are higher than among car users, while these samples do not differ significantly in terms of age and education levels, two key predictors of digital skills. In addition, individuals who use public transport more or just as much as the car report significantly higher digital skills. Both results hint at the fact that digital travel information may not require the same level of skills for car and public transport use.

Older adults, people in households with an income below modal, people with a lower education level and women are more likely to report lower digital skills and experience in transport, confirming early findings in transport research. The same individuals are less likely to use a smartphone for travel information purposes, as are those who infrequently undertake unfamiliar trips. In addition, our study shows that digital skills are a strong predictor for the use of smartphone-based travel information services and mediate the relationship between smartphone use on the one hand, and income, education level, age and frequency of unfamiliar trips on the other hand. This mediation effects applies more in the context of public transport.

Perceptions of necessity

In this study, we have also operationalised the notion of 'perception of necessity' into the concept of indispensability, inspired by Lupač (2018). Our results show that digital technologies have become embedded in travelling practices: 69% of car users and 81% of public transport users think that travelling is more difficult nowadays without a smartphone in the Netherlands. On average though, public transport users and car users do not differ in terms of perceptions of indispensability of digital technologies in transport. However, viable alternatives to digital travel information sources do exist and are still used by a majority of car and public transport users.

Nevertheless, signs along the road or in public transport are not deemed sufficient anymore to travel worry-free, as about a quarter of car and public transport travellers report. Those reporting lower digital skills do not tend to use these traditional communication channels more than those reporting higher digital skills. Public transport travellers requesting the help of friends and family or staff to look for travel information are more likely to report lower digital skills though.

While we only measured perceptions of indispensability, they contribute to shaping reality and transmitting societal norms. A widespread societal expectation to be digitally equipped and savvy can put those (temporarily) without (the required hardware/skills) at a disadvantage.

6.1.2 Which individuals are most at risk of being disadvantaged by the increasing digitalisation of transport services, what do we know about the barriers that they face with digital transformations and how these barriers impact people's mobility and accessibility of locations? (Chapter 3)

In communication science, studying disparities in terms of ICT appropriation and the consequences of such disparities is known as digital inequality research. Previous reviews on the intersection between ICTs and mobility did not cover this angle, and insights on this topic were fragmented. This study structures these insights using a conceptual framework derived from communication science research, and focuses on transport services, such as public transport and shared mobility services.

Determinants of digital access and engagement

Our review of 25 papers shows that, as of 2020, there was a burgeoning interest in the unequal access to and engagement with ICTs in transport services. Older adults, women, people with lower education levels, with lower income levels, from minorities and from rural areas are found to be more likely to be vulnerable to digitalisation in transport services. Health and literacy also play a role in difficulties dealing with digitalisation in transport services. Importantly, combinations of these determinants usually explain better a reduced access to digital technologies than e.g. age alone. Literature acknowledges that digital inequality in transport services is likely to follow and reinforce patterns of social inequality, in line with literature on digital inequality in general.

Overview of barriers

Digital inequality is a multi-layered process, and the reviewed papers usually focus on one or two types of factors of access as barriers: motivations and attitudes, material access to digital technologies, digital skills and engagement with (or usage of) ICTs. Motivations and attitudes are most frequently investigated and can be summarised as two sets of issues: rejection of technology due to a perceived lack of trust, security, privacy and reliability, as well as lack of interest in ICTs. The lack of smartphone is commonly mentioned as a barrier, given the role this device has taken within one decade (the 2010s) in transport services. Nuances in material access are discussed by a few papers. Ownership of a device is not everything, and device maintenance, connectivity, quality and an up-to-date operating system are also recognised as crucial aspects of material access. The importance of digital skills and a diversity and frequency of usage are recognised by literature, but empirical research on these factors remains scarce.

Literature highlights two pathways in which the technical characteristics of digital technologies can impact transport services people have access to: through a lack of usability and through an increasingly heavy reliance on data and algorithms. Both aspects can create exclusionary environments. The second aspect especially applies to shared mobility services and connects to literature on platform and splintering urbanism. Together, these concepts describe the fragmentation of urban infrastructure and services by digital platforms that exacerbate existing inequalities.

Impacts on people's mobility and accessibility of locations

As digital technologies become increasingly embedded in transport services, there is a risk that a relative disadvantage turns into an absolute disadvantage. For instance, people can only avoid digital payments for a time, until it becomes the default or the sole payment option. Some scholars caution that such a digital push is particularly questionable in the case of a public service such as public transport, or when shared mobility modes are being scaled up.

Negative outcomes reported in the literature are fewer trips due (at least in part) to digital transformations. Empirical evidence on how digital inequality impacts accessibility of locations and contributes to other forms of transport disadvantages and transport-related social exclusion is still scarce though. Besides, digitalisation in transport services is not a black-and-white situation, even for individuals who are more at risk of being disadvantaged by digitalisation. Indeed, there are also positive outcomes linked to digitalisation, such as accessibility features that address impairment and language barriers.

6.1.3 How do groups that are more at risk of digital inequality experience digital transformations in public transport, and what are the coping strategies they might have developed in response to it? (Chapter 4)

To answer this research question, we conducted 39 one-on-one interviews with older adults, people with a lower education level, people with impairments and people with a migration background in the Netherlands. We sampled individuals who have some difficulties using digital technologies, and with various levels of experience with public transport.

Experiences of digital transformations in public transport

These interviews confirm a result from our literature review (Chapter 3): one can reap benefits of digitalisation and experience difficulties at the same time. Access to travel information and smart cards have brought benefits among many of the participants, especially among frequent public transport users and the more digitally self-reliant ones. Low digital skills, not using digital technologies on-the-go, not possessing the right devices and a complex design of technologies raise difficulties. Besides, digital transformations (implicitly) ask travellers to be flexible and adapt to the constant changes brought about by digitalisation, such as app updates, cash money being phased out or fewer ticket offices. Some participants report instances in which they were expected to a smartphone and know how and where to find public transport information on it, mirroring the findings from Chapter 2 on perceptions of indispensability.

Coping strategies

Nevertheless, experiencing difficulties with digitalisation in public transport does not systematically translate into disadvantages for the access to and use of public transport, even for those who are less digitally self-reliant. Coping strategies serve a clear purpose here. They may even result in people becoming more digitally self-reliant when using public transport, for instance when individuals' social network or a member of public transport staff helps to remove a one-time barrier.

Support from the social network, such as a partner, children or friends is the most common form of coping strategy used by participants. Formal sources of support, from volunteers or courses, or support within the transport system itself (e.g. from staff) can also help in certain circumstances. However, these strategies can also involve pitfalls, such as hidden work, costs and stress, like extra preparation or a detour to find a service desk. In the language of transport planners, using these coping strategies would amount to raising generalised costs, where travel costs, travel time and comfort components are impacted. However, these extra efforts usually go unnoticed to the outside world.

Our study highlights the existence of a self-reliance paradox: while digital technologies have contributed to fostering self-reliance among many, those who are less comfortable with these technologies are likely to become even less self-reliant, frequently requiring support from others. Yet even support from individuals' social network can sometimes prove inadequate or insufficient. Furthermore, we see evidence that digitalisation can also contribute to driving some people away from public transport. They might fall back on private means of transport, if available, travel less or less far or even renounce some activity opportunities. Participants who experience the most problems with digital technologies are the ones with fewer opportunities to receive high-quality support. They also usually mentioned other forms of transport disadvantage, like financial barriers to travel. Our research therefore shows evidence that social and digital inequality can be mutually amplifying in the context of transport.

6.1.4 What are possible policy approaches to mitigate digital inequality in public transport? (Chapter 5)

To investigate approaches to mitigate digital inequality in public transport, we conducted 22 interviews with experts working either in the public transport sector or in other sectors also dealing with digitalisation, such as healthcare and public administration.

Our results show that there are multiple, complementary perspectives to mitigate digital inequality in public transport. We detailed each perspective in two to four measures, applicable by various transport stakeholders. First, an inclusive design increases the relevance and usability of digital technologies for a wide range of users (design perspective). Involving users early in the design process, encouraging diversity in design teams, and raising awareness about the diversity of user needs among developers also belong to this perspective. Second, retaining quality non-digital alternatives, collaborating with interest groups and non-profit organisations, as well as using low-tech tools can help provide access to public transport for people who would otherwise drop out (social perspective). Better information can help to increase the awareness of the benefits of digital technologies (persuasive perspective). Trainings can increase the confidence to get started with digital tools (educational perspective). The role of the public transport staff ought not to be underestimated by public transport authorities and operators. Workers at the interface between the system and users of the system play a key role in the digital transition. Finally, securing the issue of unequal access to public transport due to digitalisation at a decision-making level is essential: (semi-)public organisations and operators need to reappropriate themselves the governance of digitalisation in the sector. This means taking a proactive stance in identifying and addressing bottlenecks and dilemmas around digitalisation in public transport.

Nevertheless, there is only so much that the transport sector can do. Tackling more systemic issues that often underlie digital barriers like poverty and low literacy is crucially important. Cooperation between sectors is needed to secure access to public transport now and in the future to a broad group of travellers.

Our study demonstrates the scientific and policy relevance of an interdisciplinary approach. A clear added value of involving experts from other fields such as health and public administration is that they often had a more overarching view of ways to mitigate digital inequality. They paid closer attention to unintended consequences of measures, delays, and the importance of seeking collaborations. Notably, they explained the need for a governance perspective and possible actions to take in a more articulate way, reflecting a more mature understanding of the ins and outs of pervasive digitalisation.

6.2 Discussion on the context of this research

In this section, we discuss the link of this research with transport equity research (6.2.1), outcomes of access to and engagement with technologies (6.2.2), the extent to which digitalisation creates new problems (6.2.3) and the generalisability of our results (6.2.4).

6.2.1 Link with transport equity research

This dissertation contributes to research on transport equity as it seeks to understand disparities in access to and engagement with digital technologies and resulting differential impacts. We intentionally focused more on people who are likely to face challenges with pervasive digitalisation. Indeed, this was a research gap within an ever-growing body of literature focusing mainly on promises and benefits of digital transformations in public transport. Our research leads us to conclude that public transport users in the Netherlands are increasingly expected to rely on digital technologies. In this context, existing and persisting disparities in access to and engagement with digital technologies, already patterned along the lines of socioeconomic status, gender, age, geography, and ethnicity can lead to (more) difficulties using a transport system qualified as 'public'. This leads us to assess that the public transport system in the Netherlands does not fully live up to ideas and ideals of inclusiveness as laid out in European or national policy and political documents (e.g. Dutch Ministry of Infrastructure and Water Management (2021, 2022); Dutch Ministry of Health, Welfare and Sport (2024); European Commission, 2020). We therefore present ways for decision-makers and practitioners to foster a more inclusive public transport system without overly compromising on the benefits that many reap from digitalisation.

Lucas and Martens (2019) advocate for research in transport equity to focus on people's perceptions and experiences, which is what this dissertation did. Chapter 2 shows that using a smartphone to retrieve travel information for public transport is perceived as normal among public transport users in the Netherlands; yet as Lucas et al. (2019) write, 'what is considered to be the general norm for the majority within a society is not necessarily fair for everyone living within it.' (p.7). Lucas and colleagues named the car as a prime example to illustrate this; based on the quantitative insights from Chapter 2 and the qualitative insights from Chapter 4, digital technologies in transport services could also be used as an example. Chapter 4 highlights situations that may be experienced as unfair by individuals.

Nevertheless, our research does not assess the equity impacts of the implementation of digital technologies in public transport. Indeed, we have not defined a 'morally proper' distribution of benefits and burdens of these technologies among members of society, as equity assessments require (Martens et al., 2019). Throughout this dissertation, we employed the term 'inequality' (as in 'digital inequalities') in a descriptive way (Lucas et al., 2019). We do not posit that one should strive for equality in digital access and engagement in transport. Besides, our research only focuses on a specific type of impact of the pervasive implementation of digital technologies in transport, namely potential difficulties travelling and reaching destinations. Broader social, ethical and legal challenges emerging from the use of ICTs in transport contexts, such as surveillance, profiling and privacy would also need to be taken into account to assess equity impacts (Herzogenrath-Amelung et al., 2015; Zijlstra & Huang, 2023).

6.2.2 Outcomes of accessing and engaging with technologies

It is important to acknowledge that access to and engagement with digital technologies in transport are not end goals in and of themselves. The outcomes of travelling (mobility), and

especially reaching necessary and important activity opportunities (accessibility) as well as well-being are more important (Martens et al., 2019; Ryan & Wretstrand, 2019). This is where digital inequality research converges with transport/mobility research. Recent digital inequality research underlines that what people make or do not make of digital engagement is what matters, more than digital engagement itself (Helsper, 2021; Van Deursen & Helsper, 2015).

However, most of the reviewed literature in Chapter 3 does not elaborate much on outcomes of low levels of digital engagement. When they do so, mobility tends to be the focus point, rather than accessibility, social in- or exclusion, or well-being. We took mobility and accessibility of locations into account in this dissertation, albeit more conceptually than empirically. Our conceptual framework (see Figure 1.1) explicitly distinguishes between access to and engagement with digital technologies on the one hand, and participation outcomes on the other hand. The notions of mobility and accessibility are part of research gap 2 and research question 2, and the literature review in Chapter 3 explicitly addresses participation outcomes, including benefits reaped by travellers. Empirically, Chapter 4 provides evidence that difficulties in accessing digital technologies can translate into difficulties travelling and reaching destinations, especially when other social and transport disadvantages are present. Yet the nature of individuals' unmet accessibility needs and impacts on well-being and inclusion have not been addressed. This is a limitation of this dissertation.

Digital tools can also provide benefits that may alleviate existing disadvantages and have a positive impact on travelling and accessibility. For instance, the interviews in Chapter 4 showed that the Dutch smart card allowed some participants to travel more and to avoid complicated ticket vending machines.

Talking in terms of outcomes automatically requires a broader perspective, one that looks further than only the digital dimension of transport-related social exclusion. In-depth qualitative interviews in the Netherlands with a broader focus on accessibility poverty show that difficulties with digitalisation are not the most commonly cited barriers, but are recurring ones nonetheless (Drechsel, 2024; Krabbenborg & Uitbeijerse, 2023). Chapters 3 and 4 show and acknowledge that individuals having issues with digitalisation in transport may face other difficulties, such as financial barriers to travel. Chapter 4 shows that social and digital inequality can be mutually amplifying in the context of transport; this is why authors advocate for the use of 'socio-digital inequalities' (Helsper, 2021), or 'socioeconomic and digital inequalities' (Dodel & Hernandez, 2025) instead of 'digital inequalities'.

6.2.3 Not a new problem?

One may question the weight of digitalisation in difficulties travelling: of all the people encountering difficulties because of digitalisation nowadays, how many also had difficulties when everything was printed and analogue? We do not have an answer to this question but offer here some considerations. On the one hand, literature shows that difficulties accessing, understanding and using travel information are not exclusive to the digital age: people also had these difficulties when most information was printed (Cain, 2007). Low literacy and numeracy levels also hinder access to printed media. Digitalisation has undeniably made travel

information more accessible to a larger group of individuals (Vecchio & Tricarico, 2018), especially inexperienced travellers (Canzler & Knie, 2016). The wide palette of customisation digital technologies allow for can provide personalised assistance to people who may otherwise not or sparsely travel. For instance, transport applications and websites can provide features that address language barriers, impairments and low-income issues (Bekiaris et al., 2009; Gebresselassie & Sanchez, 2018). People with complex communication needs can enjoy having access to information through the internet as it spares them direct interactions (Bigby et al., 2019).

On the other hand, digitalisation is not simply about converting analogue information into bits and bytes. It brings with it new organisation structures that fundamentally transform society (Benkler, 2006). These are 'soft impacts', co-produced by users and invited, rather than strictly speaking caused by, technologies (Swierstra, 2015). Studies outside of transport (Lee & Žarnic, 2024) and Chapter 4 of this dissertation provide empirical evidence of these new structures and practices. Dealing with the new, more or less formal rules that digitalisation brings along can be a challenge for some people, requires a meta skill called digital flexibility. Finally, even in the case that digitalisation would not create new problems, it does not mean that these problems and the people affected by them are not worth paying attention to.

6.2.4 Generalisability

Qualitative and case studies are often criticised for their lack of generalisability, and this dissertation may face similar criticism. Yet there is not one way to think about generalisation. According to Firestone (1993) and Smith (2018), the concept of generalisability can be declined into three main models: statistical-probabilistic, analytical and case-to-case generalisability. The first one is often what researchers mostly working with quantitative methods refer to. However, this dissertation has more of an analytical and case-to-case generalisability.

The specific contexts or situations in this dissertation are not generalisable, but the concepts and theories are. This is analytical generalisability. Through rigorous (inductive) analyses in Chapters 4 and 5, together with the use of confirmatory strategies that address the credibility of our findings, we came to generalisations, such as our process model of coping (Chapter 4) and our list of measures (Chapter 5). Further research will have to confirm the extent to which these concepts hold, as is usual in science.

Case-to-case generalisability is also called transferability. It involves applying findings from an inquiry to a different group of people or setting (Polit & Beck, 2010). Transferability is made possible through detailed descriptions about our context in Chapters 2, 4 and 5, or thick descriptions, so that the reader can 'evaluate the extent to which the findings apply to new situations. It is the readers and users of research who "transfer" the results' (Polit & Beck, 2010, p.1453). As such, it is not up to us to assess where our findings can be transferred. However, we can expect that countries that are working towards implementing a more uniform and digital payment or travel information system in public transport will find some of our insights useful. For instance, there is a friction in striving for inclusive services while implementing more digital

tools in transport; strategies like involving diverse user groups early in the design process and retaining some non-digital elements are helpful.

6.3 Implications for practice

In Chapters 2, 3 and 4, we have seen that digital technologies can constrain access to public transport for some individuals who may already be disadvantaged, and even hinder it altogether. This becomes especially problematic when digital transformations are ubiquitous. Chapter 5 provided strategies for policymakers and practitioners alike to address these problems in public transport. As more and more transport services are embracing digital transformations, many of these strategies could also be transferred to transport services in general, such as shared mobility modes.

However, the measures presented in Chapter 5 come at a cost for service providers, operators, transport authorities and/or governmental organisations. While some call to ensure that all transport services are accessible for all people with difficulties dealing with digitalisation, we argue that striving for the inclusion of every single person in all transport services is unrealistic. Still, efforts to foster inclusive services in the digital era should not be made indiscriminately. To this end, we suggest a matrix to determine the extent to which decision-makers and practitioners should give attention to the inclusivity of a service in the digital era. This matrix is presented in Figure 6.1.

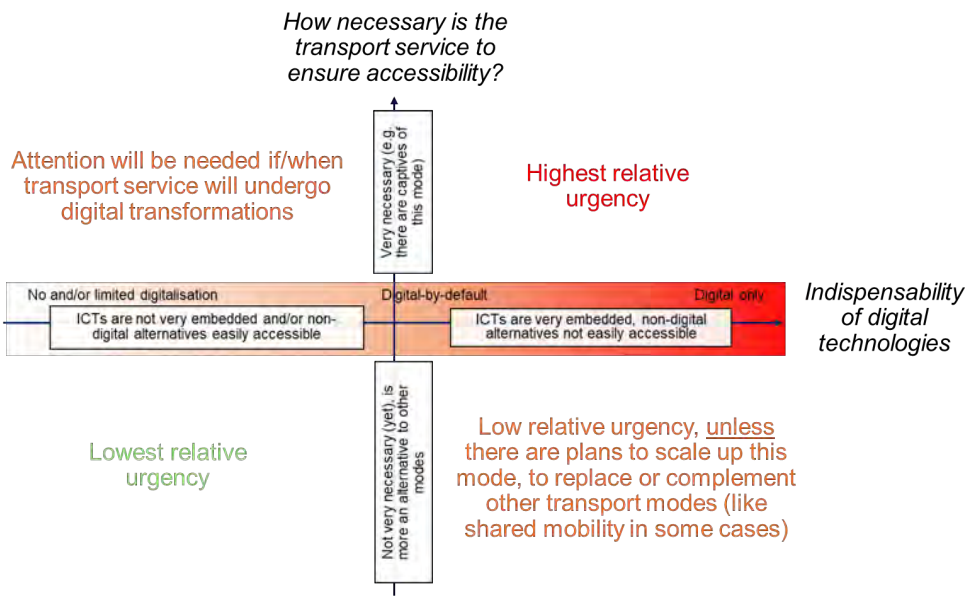

Figure 6.1: Where do policymakers and the transport sector need to direct efforts? Matrix of indispensability of digital technologies versus transport service's necessity.

The vertical axis of the matrix is about how necessary a transport service is to enable accessibility among the population. There may be a (political) choice to consider that a certain transport mode is necessary (at a certain place and time). Or decision-makers may judge a transport mode necessary when enough people depend on it to reach destinations. Such a consideration necessitates judgments requiring decision-makers to be clear about the equity notions they are using (Alonso-González et al., 2022). It can be helpful to know the share of people who are captives to the transport mode. For instance, we know that 10% of bus users in the Netherlands would not have made their last bus trip, had there been no bus available (Zijlstra et al., 2018). It is likely that these individuals are bus captives.

The horizontal axis of this matrix is about how indispensable digital technologies are to access the service. Here, we take the definition of indispensability used throughout this dissertation and based on Lupač's work (Lupač, 2018). How indispensable a digital engagement is, is highly contextual and depends on two aspects:

- The level of embeddedness of a given digital technology in everyday routines,
- The availability of non-ICT alternatives, factoring in potential costs (time, money, energy, effort, etc.) to access these alternatives.

Again, these aspects need to be carefully considered by decision-makers, and studies such as the ones presented in Chapters 2 and 4 help to assess the level of indispensability. Another way to think about indispensability is to evaluate the extent to which a system is 'digital-only' or has become 'digital-by-default'. When properly implemented, the latter can still include quality non-digital alternatives, hence its position leaning to the middle in Figure 6.1.

Based on these considerations, we can argue that public transport in the Netherlands may be placed in the upper middle-right part of the matrix. Indeed, both policy and political documents emphasise the importance of public transport (Coalition agreement Schoof, 2024; Dutch Ministry of Infrastructure and Water Management, 2021) and this dissertation shows that public transport has moved/is moving from the left to the right quadrant in the past decades. Shared mobility services such as shared bikes would likely be placed in the lower right quadrant of Figure 6.1. Indeed, they heavily (or only) rely on a digital access by users and are currently more alternatives to other modes, than modes with captive users at the moment (at least in Europe). Should they be scaled up to complement and potentially replace public transport in some areas, they could move to the upper right quadrant of Figure 6.1.

It is important for policymakers and practitioners to bear in mind that systems do not accidentally become 'digital-by-default'. This is the result of policies implemented by providers, operators and/or governmental organisations, with the goal to enhance efficiency, accessibility, and user experience through self-service solutions. If the public sector and governments are to become increasingly reliant on (corporate) digital ecosystems (such as Uber, MaaS platforms, …), it is crucial for them to think carefully about the principles from which these systems are designed (Van Dijck et al., 2018) and to work to mitigate unintended consequences. The reflections on governance from Chapter 5 apply here.

Public transport in the Netherlands is no exception. In recent years, public (administration) services in many industrialised countries have also progressively digitalised (Mariën & Van Damme, 2016; Peeters & Widlak, 2018). The Digital Government Information Points in Dutch libraries mentioned in Chapter 5 are a direct result of Dutch public administration services realising that digitalisation had gone too far. Some citizens need a physical service point to carry out administrative procedures. In November 2024, the Walloon region in Belgium passed a decree requiring all public (administrative) services to provide physical service points, a telephone service *and* contact via postal mail (Parlement Wallon, 2024).

Ultimately, Cohen and Jones (2020) remind us that tech actors have a lot to gain in selling the public stories about the immediacy and the inevitability of technologies, 'which can give rise to a feeling of panic in the policy maker' (p. 81) who would not know how to address these transformations taking properly into account their social impacts. Nevertheless, what can appear as a self-driving force is not immune to change: technology shapes society, but the other way around is also true (Van Dijck et al., 2018).

6.4 Future research directions

In addition to the future research directions outlined at the end of each chapter, we highlight here several key areas where further research would be valuable, based on our overall findings.

6.4.1 Assessing prevalence

A question that remains unanswered after this dissertation pertains to the prevalence of difficulties in accessing public transport due to digital transformations. Answering this question is relevant because it would give policymakers a clear picture of how big the group of people experiencing problems is and subsequently help to catalyse action. However, this is a challenging exercise. A first challenge lies in the fact that individuals encountering barriers due to digitalisation may face other barriers to travel, as we have seen in Chapters 3 and 4. In fact, many dimensions of transport disadvantage overlap and do not usually happen in isolation (Combs et al., 2016; Krabbenborg & Uitbeijerse, 2023). The second challenge lies in data collection, especially because an online-only data collection method, which is quite common nowadays, is likely to under-sample individuals having difficulties accessing and engaging with digital technologies.

A common and straightforward way to answer this question is to use statistics on illiteracy or digital access. For instance, 10% of Dutch adults do not have access to internet on a smartphone (Van Deursen, 2023). Based on that, one may infer that it can't be expected that people have access to online travel information and payment systems for public transport in the Netherlands. However, this approach is unsatisfying as it does not focus on transport and ignores personal and situational specificities. Data collected within the EU-funded DIGNITY project in 2020-2021 (Goodman-Deane et al., 2024) and SmartHubs project in 2022-2023 (Gkavra et al., 2024) through in-person surveys on the (barriers to) use of digital mobility services is helpful here. For instance, in Germany, Goodman-Deane et al. (2021) found that 56.6% of older adults,

55.6% of people with disabilities and 43.6% of those with low education levels report feeling very limited in their travel because digital skills are needed to either plan travel or use transport. However, even with quota sampling methods, these studies note that some groups tend to be underrepresented and hard to reach (Goodman-Deane et al., 2024; Gkavra et al., 2024). This was unfortunately the case for the Dutch sample of the DIGNITY project which under-sampled older adults with impairments[15], but the analysis of this dataset could already certainly yield insightful results.

Importantly, future quantitative studies need to consider outcomes, as explained in section 6.2.2. Dodel and Hernandez (2025) have started doing so but could only consider mobility-related outcomes based on their datasets. Their outcomes were about people's ability to check the schedule of buses, search for addresses and order transport. Accessibility-based outcomes, or outcomes in terms of unmet travel needs, would also be useful to better understand negative consequences of digitalisation. For instance: are there places people are unable to reach because of difficulties triggered by digital transformations? Because filling in online surveys remains convenient for many and cost-efficient, hybrid survey designs could be helpful for researchers wishing to tackle this topic. For instance, Durand and Zijlstra (2023) combined web-based and phone-assisted surveys to reach users of Special Transport Services (or paratransit) in the Netherlands. The original sampling was not only based on a large online panel, but also used snowballing to reach individuals who may not be part of such large online panels. The use of a phone survey also helps to bypass the non-negligeable issues of low literacy and numeracy levels.

6.4.2 More fine-grained insights on older adults

A strong point of this dissertation is that we showed that the group of individuals who might be at a disadvantage due to digitalisation is broader than older adults only. Nevertheless, there are reasons to dedicate attention to this group of people. 'Older adults' refers to a very heterogenous group of individuals (Drechsel, 2024; Durand & Zijlstra, 2023; Ravensbergen et al., 2022; Van Gorp, 2019). This heterogeneity is seldom acknowledged. Two individuals reaching old age may have had very different life trajectories, leading to differences in abilities, capabilities and practices. For instance, interviews conducted by Durand et al. (2023b) among first-generation older adults in the Netherlands reveal the rich diversity within this group and illustrate how these differences can lead to varied mobility and accessibility outcomes. Ravensbergen et al. (2022) note that research tends to oversimplify this group and focus on easy-to-reach individuals. In Chapter 4, we saw that adults aged 65 to 74 with a medium to higher education level and without a migration background encounter fewer difficulties with digitalisation in transport services. Although we cannot generalise this result to the population of the Netherlands, this finding hints at the fact that researchers investigating barriers to travel and potentially exclusionary effects due to digitalisation in transport need to look beyond this relatively easy-to-reach group.

[15] Based on the author's own communication with the DIGNITY project team.

There is also a societal relevance to focus on older adults. The share of those aged 80 years or above is projected to increase from 5.8% to 14.6% between 2019 and 2100 in Europe (Eurostat, 2020). Older adults are increasingly expected to travel independently (Schwanen et al., 2012), but most people who get to be old enough will eventually have to cease driving due to health limitations. Even though older drivers do not usually plan well for eventual driving cessation (Liddle et al., 2004), evidence suggests that older individuals will use public transport where it is accessible and provided at a reasonable service level (Currie & Delbosc, 2010a). In Chapter 2, we established that individuals who are more used to driving than to using public transport report significantly lower digital skills for transport-related purposes. Low digital skills, or a perception of low digital skills, could therefore hinder the transition to public transport of individuals who have been mostly drivers their whole life. It is worth zooming in on people who are making or might have to make this transition. Research from Schmitt et al. (2019) might be a useful source of inspiration for this inquiry.

The potential transition from Special Transport Services (or paratransit) to public transport is also interesting to study. Research from the Netherlands shows that finding travel information, orienting oneself in the public transport system and buying a ticket are main obstacles for paratransit users to make use of public transport (Durand & Zijlstra, 2023). A large majority of these individuals is aged 75 and above and does not rely on the internet to book paratransit services (while such an option does usually exist). Given the financial constraints paratransit services are facing, it is worth zooming in on ways to facilitate public transport use for paratransit users – without forgetting that public transport may not be a panacea to substitute Special Transport Services (Durand & Zijlstra, 2023).

In terms of methods, considerations from section 6.4.1 on quantitative research and the method employed in Chapter 4 can be useful. Besides, we encourage future qualitative research to explore other ways than direct questioning of ‘at-risk’ individuals. As people age and face mental, physical or cognitive challenges, they may come to accept that using public transport outside of their usual environment is not possible and that some activities are no longer accessible. This makes it difficult to identify unmet travel needs through direct questioning alone. Using tools such as maps (Drechsel, 2024; Vecchio, 2020), group discussions (Nordbakke, 2013) or explorative diaries (Nyblom, 2014) could also be useful. Furthermore, we strived to let participants speak for themselves and to distinguish between what they were telling us and how we – as able-bodied, digitally skilled individuals – interpreted it, but it would have been valuable to involve key informants to enrich our analysis. Volunteers in the community, caregivers, social service workers, citizen advisory committee members, adult education coordinators… the list of potential key informants is large. Involving them can allow to uncover what someone might be unable to formulate or does not want to tell, as addressed by Shay et al. (2016) and Drechsel (2024).

6.4.3 Skills

In Chapter 3, we established that there are multiple categories of digital skills, from medium- to content-related skills. Yet we did not make such distinctions in Chapter 2. In the past few

years, some studies have started to operationalise more the types of digital skills that are needed to navigate transport services, see for instance Horjus et al. (2022) and Goodman-Deane et al. (2021). However, these studies are not explicit on the exact types of skills that people need to travel. Future research could get inspired from communication science research (Van Deursen & Van Dijk, 2014) to explore this topic. Having a better understanding of skills could allow to better support individuals who struggle with this access factor. This is also relevant with the development of new digital services in transport (see 6.4.4. below), which may require new types of skills. We know for instance that a majority of internet users do not understand how information results are presented to them and are unable to critically assess them (Ofcom, 2017; Van Deursen, 2023), which might become an important skill in transport (including tourism) in the future.

Another interesting area to explore pertains to the relationship between travel experience and digital skills. We established a correlation between these two aspects in Chapter 2 but could not make statements on causality links, which is a limitation of our work. People who travel more, likely had to acquire digital skills to look for travel information, if they did not possess them already. At the same time, having sufficient digital skills to look for travel information might also foster the possibility to travel. Such research would contribute to nascent research on the relationships between literacies and travelling (Hong et al., 2020).

6.4.4 New digital services

Digital transformations will keep unfolding in transport in coming decades. Since it is difficult to research the impact of digital technologies when they have already become embedded in daily practices (Durand et al., 2023a; Line et al., 2011), we encourage researchers to view the introduction or upscaling of digital services as opportunities to conduct before-and-after studies. An example of such a study is the work done by Pritchard et al. (2015) on the phasing out of cash in buses in London. In the Netherlands, the introduction of OVpay, a new integrated payment system, paired with the phasing out of the current smart card (Ov-chipcard), could also be interesting.

In general, we encourage researchers to investigate the ins and outs of new and/or expanding digital services and products, with a special attention to how they impact populations who might already be disadvantaged. These impacts could be negative as well as positive. Examples of such services and products are shared mobility modes, parking applications and new-generation electric vehicles, which typically require a higher level of digital access of its users than other types of cars did or do (Eskenazi et al., 2017). Such investigations are especially relevant if these services and modes are to be scaled up, which we already know to be the case for electric vehicles. Research on the equity impacts of shared mobility modes has flourished in the past years (De Ruijter et al., 2024; Garritsen et al., 2024; Groth et al., 2023). However, studies usually either focus on geographical accessibility impacts, or on digital barriers. Based on our literature review (Chapter 3), we suggest that investigating these aspects simultaneously is important to map out the full scale of potential consequences of these modes being made more widely available (see also Lucas et al. (2019)). In terms of methods, we refer to Sherriff et al.

(2020) for inspiration, who used a mixed-methods approach with a questionnaire and one-on-one phone interviews.

As mentioned in section 6.3.2, accessing and engaging with digital technologies is not a goal in and of itself. If policymakers' goal is to ensure that people have access to certain services, then digital tools might be a solution to keep offering services in remote areas, such as a store with a digital lock or locker boxes for parcel delivery (Di Ciommo et al., 2023; Stjernborg & Svensson, 2024). These solutions might help to mitigate and counteract accessibility poverty in these areas, by improving inhabitants' possibilities to reach services in a reasonable time, and at a reasonable cost (also for authorities and businesses). Nevertheless, these services need to be developed and implemented with a careful consideration for end users and preferably with their participation (Di Ciommo et al., 2023). Otherwise, these solutions risk reinforcing a 'vicious digital circle' (Warren, 2007), or as explained in Chapter 3, turning relative disadvantages into absolute ones.

Appendices

Appendix A

Table A.1: Representativeness of the sample of car users.

Variable		**Car users Dutch national travel survey (ODiN), 2022**	**Car users MPN after weighing (N=972), 2022**
Gender	Men	49.5%	49.6%
	Women	50.5%	50.4%
	Non-binary or gender diverse	-	-
	Prefer not to disclose	-	-
Age	18-24	8.8%	8.2%
	25-34	16.1%	17%
	35-44	17.4%	18.5%
	45-54	19.2%	19.7%
	55-64	19%	18.8%
	65 and older	19.5%	17.9%
Education	Basic, secondary and basic vocational	16%	16.2%
	(Advanced) vocational and college	34.8%	35%
	University (academic education)	49.1%	48.8%
Car use frequency	4 times or more per week	42%	42%
	Once to 3 times a week	40.2%	40.2%
	Once to three times per month	14.8%	14.8%
	Between 6 and 11 times per year	3%	3%

Table A.2: Representativeness of the sample of PT users.

Variable		**PT users Dutch national travel survey (ODiN), 2022**	**PT users MPN after weighing (N=685), 2022**
Gender	Men	45.9%	42.6%
	Women	54.1%	57.4%
	Non-binary or gender diverse	-	-
	Prefer not to disclose	-	-
Age	18-24	17.6%	15.5%
	25-34	19.8%	20.5%
	35-44	16.1%	16.7%
	45-54	15.5%	15.5%
	55-64	15%	15.9%
	65 and older	16%	15.9%
Education	Basic, secondary and basic vocational	13.3%	12.6%
	(Advanced) vocational and college	32.2%	32.6%
	University (academic education)	54.5%	54.8%
PT use frequency	4 times or more per week	9.2%	9.2%
	Once to 3 times a week	17.8%	17.8%
	Once to three times per month	23%	23%
	Between 6 and 11 times per year	50%	50%

Appendix B

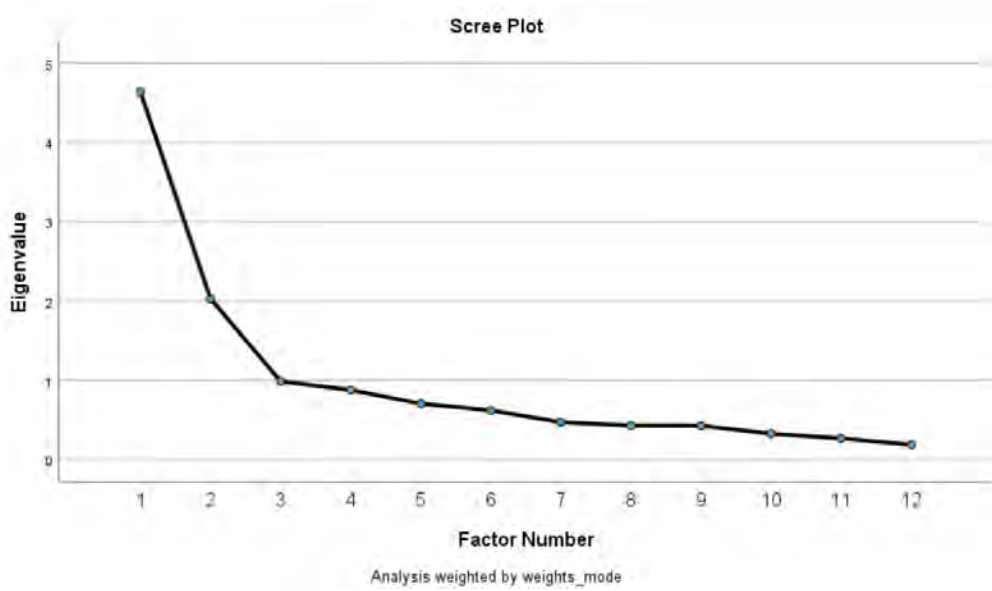

Figure B.1: Scree plot of the Exploratory Factor Analysis.

Appendix C

Table C.1: Composition of the final sample based on personal and mobility characteristics.

Characteristic	**Categories**	**Number**
Gender	Woman	24
	Man	15
Age	Younger than 65 (17-64 years old)	12
	65 to 74 years old	17
	75 years old and older	10
Education level (according to Statistics Netherlands)	Higher education level	8
	Middle education level	8
	Lower education level	23
Province (8 out of the 12 provinces are represented)	Friesland	1
	Gelderland	4
	Groningen	1
	North Brabant	2
	North Holland	10
	Overijssel	2
	Utrecht	15
	South Holland	4
Migration background	Yes	10
	No	29
Ownership of an ov-chipcard	Yes	28
	No	11
Use of bus/tram/metro	Yes	27
	No	12
Train use	Yes	28
	No	11
Bike use	Yes	31
	No	8
Car use	Yes	8
	Limited (usually rides along with someone else from the household or prefers to avoid driving)	9
	No	22

Appendix D

Table D.1: Summary of the interviewed public transport experts. Five of them identified as women, six of them identified as men.

#	Name of organisation	Position of interviewed expert	Experience of expert in this position or similar one (only if linked with public transport and accessibility)
1	Dutch Ministry of Infrastructure and Water Management	Senior policymaker in public transport accessibility	5-10 years
2		Senior policymaker in smart mobility	10-15 years
3	PBL Netherlands Environmental Assessment Agency	Senior researcher in urbanisation and transport	15-20 years
4		Senior researcher in urbanisation and transport	5-10 years
5	NS (Dutch national railway company)	Channel management manager	10-15 years
6	9292 (national multimodal trip planner)	Specialist in relations with PT travellers	10-15 years
7	Public transport ombudsman		1-5 years
8	Rover (public transport travellers' organisation)	Director	5-10 years
9		Policymaker	1-5 year
10	Radboud University	Researcher in transport and justice	15-20 years
11	Delft University of Technology	Researcher in design of mobility services	5-10 years

Table D.2: Summary of the interviewed experts outside the public transport sector. Four of them identified as women, seven of them identified as men.

#	Name of organisation	Position of interviewed expert	Experience of expert in this position or similar one
1	Ministry of the Interior and Kingdom Relations	Senior policymaker in digital accessibility	20-25 years
2	Stichting Digisterker (organisation helping people with low digital skills)	Project leader educational programmes	5-10 years
3	Low-Tech magazine	Journalist	15-20 years
4	CAK (Central Administration Office)	Programme manager digital inclusion	15-20 years
5	Pharos (Dutch Centre of Expertise on Health Disparities)	Programme manager eHealth	5-10 years
6	National Ombudsman	Digitalisation expert	5-10 years
7		Digitalisation expert	10-15 years
8	Vrije Universiteit Brussel, Belgium	Researcher in adult education and social inclusion	10-15 years
9		Researcher in digital inclusion	10-15 years
10	Utrecht University	Researcher in media and governance	20-25 years
11	Tilburg University	Researcher in health accessibility and technology	30-35 years

Organisations represented during the workshop with Dutch public transport experts:

- CROW (Dutch knowledge platform for transport and infrastructure)
- RET ((sub)urban operator, region Rotterdam)
- GVB ((sub)urban operator, region Amsterdam)
- Arriva (regional operator)
- NS (Dutch national railway company)
- Vervoerregio Amsterdam (public transport authority, region Amsterdam)
- OV-bureau Groningen-Drenthe (public transport authority, north of the Netherlands)
- Translink (Dutch public transport data administrator)
- 9292 (national multimodal trip planner)
- Dutch Ministry of Infrastructure and Water Management

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About the author

Anne Durand was born in Montbrison, France, in 1992. In 2010, she entered the preparatory classes at the Lycée du Parc in Lyon. She then joined the École Centrale de Marseille (now Centrale Méditerranée) in 2012, training to become a generalist engineer. In 2014, she was admitted to a double-degree programme and moved to the Netherlands to specialise in transport at Delft University of Technology. In 2017, she received her Master of Science in Engineering from École Centrale de Marseille and finished valedictorian of her class. The same year, she also received her Master of Science in Transport, Infrastructure and Logistics (*cum laude*). Her master thesis project at Delft University of Technology was focusing on managing disruptions in public transport from a passenger's perspective, where Anne already showed a keen interest for a human-centred approach.

Anne started working at KiM Netherlands Institute for Transport Policy Analysis as a researcher in 2017. She was offered the opportunity to pursue a Ph.D as an external candidate at Delft University of Technology and officially started in April 2019. The choice of her dissertation's theme was motivated by her work at KiM researching Mobility-as-a-Service, where she had observed a clear knowledge gap in literature, among policymakers and practitioners. Although Anne was mainly trained to think as an engineer, her interest for social sciences has grown over the years and she likes to blend qualitative and quantitative approaches in her work. At KiM, Anne investigates travel behaviour, accessibility and the transition to a more sustainable and inclusive mobility. She completed her Ph.D. research in 2025.

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- Durand, A. (2024) Les utilisateurs de transport pour personnes à mobilité réduite face au défi des transports en commun : le cas des Pays-Bas (in French). *6ème Rencontres Francophones du Transport et de la Mobilité* (RFTM 2024), Brussels, Belgium.
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Awards

- Best paper award TRANSED 2018.

  Awarded contribution: Alternatives to Special Transport Services in the Netherlands: The perspective of mobility-impaired people.

- Cuperusprijs 2018, award issued every other year by the Dutch Royal Institute of Engineers for the best Master's Thesis in the field of transport in the Netherlands.

  Awareded work: Durand, A. (2017) Managing disruptions in public transport from the passenger perspective: A study to assess and improve operational strategies for the benefit of passengers in rail-bound urban transport systems. MSc Thesis, Delft University of Technology.

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Summary

Technological advancements have transformed how travellers access and navigate transport systems. This thesis analyses how such developments impact (potential) public transport users, especially those struggling with digital technologies. It also explores ways to mitigate potentially exclusionary effects of digitalisation in transport, helping transport operators, authorities and policymakers ensure that digitalisation does not disadvantage vulnerable users.

About the Author

Anne Durand conducted her PhD research at Delft University of Technology as an external PhD candidate while working at the KiM Netherlands Institute for Transport Policy Analysis in The Hague. Her research interests include travel behaviour, accessibility and inclusive mobility.

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